6 SOURCE ASSESSMENT – METHYLMERCURY

The Delta mercury TMDL program addresses the sources of two constituents, methyl and total mercury. The program focuses on methylmercury because, as described in Chapter 5, the Delta linkage analysis demonstrated a statistically significant, positive correlation between methylmercury levels in ambient water and fish tissue. The program also addresses total mercury for several reasons: methylmercury production has been found to be a function of the total mercury content of sediment (Chapter 3); the mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion for total recoverable mercury in freshwater sources; and the mercury control program for San Francisco Bay has assigned a total mercury load reduction of 110 kg/yr to the Central Valley (Johnson and Looker, 2004). Sources and losses of methylmercury are described in this chapter. Sources and losses of total mercury and suspended sediment are described in Chapter 7. All of the mass load calculations are based on Equation 6.1:

Equation 6.1:

$$M_x = C_x * V$$

Where: M_x = Mass of constituent, X

C_x = Concentration of constituent, X, in mass per volume

V = Volume of water

Average annual methylmercury loads were estimated for water years (WY) 2000 to 2003, a relatively dry period that encompasses the available methyl and total mercury concentration data for the major Delta inputs and exports. Section 6.1 and Appendix E describe the water volumes upon which the loads are based. Sections 6.2 and 6.3 describe the methylmercury concentration data for all major sources and sinks and identify data gaps and uncertainties. Section 6.4 reviews the results and potential implications of the methylmercury mass balance. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the measurements and of the importance of other unknown processes at work in the Delta.

6.1 Water Budget

Water inputs and losses were evaluated for the WY2000-2003 period, a relatively dry period that encompasses the available methylmercury concentration data for the major Delta inputs and exports (Section 6.2). In addition, the WY1984-2003 period was evaluated to illustrate the importance of wet years, particularly for total mercury and sediment loading from the Yolo Bypass (Chapter 7). This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. An assessment of a typical distribution of wet and dry water years is critical to the understanding of mercury and sediment sources because, given the interannual variability in Sacramento Basin flows and mercury loads, and high daily loads associated with large storm events, the load transported by several high flow days may be equivalent to the annual load from the Sacramento River Basin during a dry year (see Figure E.1 and Table I.2 in Appendices E and I, respectively).

Water volume information for Delta inputs and exports was obtained from a variety of sources. USGS and DWR gages provided daily flows for the major tributaries to the Delta. The Dayflow model was used to estimate daily flow to San Francisco Bay, the Delta Mendota Canal (DMC), and the State Water Project (SWP). The Delta Island Consumptive Use Model was used to estimate Delta agricultural diversion and return flows. Average annual precipitation and land use acreages were used to estimate wet weather inputs from urban areas, atmospheric deposition, and tributaries without flow gages. Project files were reviewed to determine average annual discharges from NPDES-permitted facilities in the Delta and annual average volumes removed by dredging projects. Appendix E provides a detailed description of the methods used to estimate annual average flow for the different water sources.

The WY2000-2003 water budget balances within about 5%, and the WY1984-2003 water budget balances to within about 1% (Table 6.1). This indicates that all major water inputs and exports have been identified. The Sacramento River, San Joaquin River and Yolo Bypass are the primary water sources, with the Sacramento River providing the majority of flow. The primary sinks are San Francisco Bay and the State and Federal pumps that transport water to the southern part of the State. The majority of water movement in the Delta is down the Sacramento River to San Francisco Bay and through a series of interconnecting channels to the State and Federal pumps. Most of the water in winter and spring flows to San Francisco Bay, while in summer and fall the State and Federal pumps export a larger fraction south of the Delta (DWR, 1995).

6.2 Methylmercury Sources

The following were identified as sources of methylmercury to the Delta/Yolo Bypass: tributary inflows from upstream watersheds, sediment flux, municipal wastewater, agricultural drainage, and urban runoff. Table 6.2 lists the average methylmercury concentrations and estimated average annual loads for each for WY2000-2003. The following sections illustrate the locations of the sources, describe the available methylmercury concentration data, and identify data gaps and uncertainties associated with the load estimates. Figures and tables cited in the text are arranged at the end of each source-specific section in the order in which they were mentioned.

Table 6.1: Average Annual Water Volumes for Delta/Yolo Bypass Inputs and Losses

Inputs & Exports	WY2000-2003		WY1984-2003	
	Water Volume (M acre-feet/yr)	% All Water	Water Volume (M acre-feet/yr)	% All Water
Tributary Sources (% of All Inputs)				
Sacramento River	15.1	75%	16.1	68%
San Joaquin River	1.8	9.0%	3.0	13%
Fremont Weir Spills to Yolo Bypass	1.1	5.5%	1.9	8.0%
Mokelumne-Cosumnes River	0.43	2.4%	0.69	2.9%
Knights Landing Ridge Cut	0.27	1.3%	0.33	1.4%
Cache Creek Settling Basin	0.22	1.1%	0.38	1.6%
Calaveras River	0.15	0.75%	0.16	0.68%
French Camp Slough	0.064	0.32%	0.067	0.28%
Willow Slough & Bypass	0.062	0.31%	0.068	0.29%
Morrison Creek	0.061	0.30%	0.064	0.27%
Putah Creek	0.041	0.20%	0.11	0.47%
Ulatis Creek	0.032	0.16%	0.033	0.14%
Bear/Mosher Creeks	0.029	0.14%	0.030	0.13%
Dixon Area	0.012	0.06%	0.012	0.05%
Marsh Creek [(a)]	0.006	0.03%	0.006	0.03%
Other Small Drainages to Delta [(b)]	0.082	0.41%	0.082	0.35%
Sum of Tributary Inputs	**19.51**	**97.1%**	**23.03**	**97.5%**
Within-Delta Sources (% of All Inputs)				
Wastewater (Municipal & Industrial)	0.27	1.4%	0.27	1.1%
Atmospheric (Direct)	0.089	0.45%	0.092	0.39%
Atmospheric (Indirect)	0.16	0.80%	0.17	0.72%
Urban	0.059	0.30%	0.061	0.26%
Sum of Within-Delta Inputs	**0.58**	**2.9%**	**0.59**	**2.5%**
Exports (% of All Exports)				
Outflows to San Francisco Bay [X2]	12	63%	17	73%
State Water Project	3.2	17%	2.6	11%
Delta Mendota Canal	2.5	13%	2.4	10%
Agricultural Diversions [(a)]	0.99	5%	0.99	4.2%
Evaporation	0.30	2%	0.3	1.3%
Dredging [(a)]	0.00024	0.001%	0.00024	0.001%
Sum of Inputs	**20.09 M acre-feet**		**23.63 M acre-feet**	
Sum of Exports	**18.99 M acre-feet**		**23.29 M acre-feet**	
Input - Export	**1.10 M acre-feet**		**0.33 M acre-feet**	
Exports / Inputs	**95%**		**99%**	

(a) Only WY2001-2003 flow data were available for Marsh Creek. Agricultural diversion volume is based on WY1999. The water volume removed by dredging is a 10-year average. The same water volumes for these inputs and exports, and for the Wastewater input, were used in both water budget periods.

(b) "Other Small Drainages to Delta" include the following areas shown on Figure 6.1, for which methylmercury, total mercury and TSS concentration data are not available: Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

Table 6.2: Methylmercury Concentrations and Loads to the Delta/Yolo Bypass for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Tributary Sources			
Sacramento River @ Freeport	2,026	39%	0.10
San Joaquin River near Vernalis	356	6.8%	0.16
Fremont Weir Spills to Yolo Bypass	177	3.4%	0.10
Cache Creek Settling Basin	137	2.6%	0.50
Mokelumne River near I-5	108	2.1%	0.17
Knights Landing Ridge Cut	100	1.9%	0.19
Calaveras River (b)	26	0.50%	0.14
Willow Slough & Bypass (a)	18	0.34%	0.24
Putah Creek	11	0.21%	0.18
Bear/Mosher Creeks (b)	11	0.21%	0.31
French Camp Slough (b)	11	0.21%	0.14
Ulatis Creek (b)	9.5	0.18%	0.24
Morrison Creek (b)	7.5	0.14%	0.10
Dixon Area (a)	3.6	0.07%	0.24
Marsh Creek @ Highway 4 (c)	1.9	0.04%	0.25
Other Small Drainages to Delta	*unknown*		
Sum of Tributary Sources	**3,004**	**58%**	**- - -**
Within-Delta Sources			
Wetland Habitats	983	19%	- - -
Open Water Habitats	861	17%	- - -
Wastewater	204	3.9%	<0.02 to 1.7
Agricultural Lands	123	2.4%	- - -
Atmospheric Deposition	23	0.44%	- - -
Urban	20	0.38%	0.24
Sum of Within-Delta/Yolo Bypass Sources	**2,215**	**42%**	**- - -**
TOTAL MeHg INPUTS:	**5,219 g/yr (5.2 kg/yr)**		

(a) Methylmercury data were not available for Willow Slough, Willow Slough Bypass, and Dixon Area runoff. The average methylmercury concentration for Ulatis Creek was used to estimate their inputs to the Yolo Bypass because they have similar land uses as the Ulatis Creek watershed.

(b) Average wet weather methylmercury concentrations are shown for the small watersheds rather than average annual concentrations.

(c) Only WY2001-2003 flow data were available for Marsh Creek.

6.2.1 Tributary Inputs

Tributaries contribute almost 60% of Delta methylmercury inputs (Table 6.2). Figure 6.1 illustrates the tributary watersheds that drain directly or indirectly to the Delta within its legal boundary. The following watershed areas drain directly to the Delta:

- Calaveras, Mokelumne, Sacramento, and San Joaquin Rivers;
- Bear, Marsh, Mosher, Morrison, and Ulatis Creeks;
- Prospect and Shag Sloughs, which drain the Yolo Bypass;
- French Camp Slough and Upper Lindsay/Cache Slough area; and
- Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

The primary drainage in the Yolo Bypass is the Toe Drain, which drains southward to Prospect Slough in the legal Delta. However, depending on the level of inundation in the Yolo Bypass, about 20% of the incoming water may drain to the Delta by way of Shag Slough (Foe *et al*., 2007). The following watershed areas drain to the Yolo Bypass upstream of Prospect and Shag Sloughs:

- Cache Creek Settling Basin
- Fremont and Sacramento Weirs
- Knights Landing Ridge Cut
- Putah Creek
- Willow Slough and Willow Slough Bypass
- Dixon Area

Putah Creek drains to the Yolo Bypass downstream of the legal Delta boundary, while the rest of the watershed areas drain to it upstream of the legal Delta boundary. Fremont and Sacramento Weirs convey floodwaters from the Sacramento and Feather Rivers, Sutter Bypass and their associated tributary watersheds. The Knights Landing Ridge Cut is an overflow channel that connects the Colusa Basin Drain to the Yolo Bypass (see Figure 6.1 and Figure E.2 in Appendix E).

Several sampling efforts have taken place to characterize tributary inputs to the Delta and Yolo Bypass. Figure 6.2 shows the tributary methylmercury monitoring locations. Appendix L provides the methylmercury concentration data collected at each tributary location and Table 6.3 and Figure 6.3 summarize the data.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling in the four major tributaries – Sacramento River, San Joaquin River, Mokelumne River, and Prospect Slough – from March 2000 to September 2001 (Foe, 2003). In addition, other programs conducted periodic aqueous methylmercury sampling on the Sacramento River between July 2000 and June 2003 (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Monthly sampling of the major tributaries and periodic sampling of other tributaries by Central Valley Water Board staff resumed in April 2003. Of the three Sacramento River sampling locations included in the linkage analysis (Chapter 5) – Freeport, River Mile 44 and Greene's Landing – Freeport is the most upstream location and is used to characterize loads from the Sacramento River watershed[34] (Table 6.2).

The Sacramento Weir did not spill to the Yolo Bypass during WY2000-2003; hence, no methylmercury load estimate was made for Sacramento Weir inputs. Methylmercury loads contributed by Fremont Weir spills were estimated using methylmercury concentration data collected from the Sacramento River at Colusa because field observations indicate that Fremont Weir spills are typically comprised of flows from the Sacramento River upstream of the Feather River confluence (Foe, pers. comm.). Methylmercury loads contributed by the Knights Landing Ridge Cut were estimated using methylmercury concentration data collected from the Colusa Basin Drain at Knights Landing.

Methylmercury data were not available for several of the small watersheds and drainage areas that discharge to the Delta and Yolo Bypass. The average methylmercury concentration for Ulatis Creek was used to estimate Willow Slough/Bypass, Upper Lindsay/Cache Slough, and Dixon area inputs because they have similar land uses as the Ulatis Creek watershed and are adjacent to each other. No methylmercury load estimates were made for the other small drainage areas (Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas); given that these areas contribute only about one third of a percent of all water inputs to the Delta/Yolo Bypass, methylmercury loads from these areas are not expected to be substantial.

Regressions between methylmercury concentration and daily flow were evaluated for each tributary input with available flow gage records to determine whether concentrations could be predicted from flow (Appendix F). Only the regression for the Sacramento River was significant ($P<0.05$). The Sacramento River regression explained 12% of the variation in methylmercury concentrations. Lack of a relationship between methylmercury concentrations and flow at all sites except the Sacramento River suggests that flow is unlikely to be a useful surrogate for methylmercury concentrations. The relationship at Freeport may be a statistical anomaly. Therefore, average methylmercury concentrations were used to estimate all tributary loads. For tributary inputs with a monthly sampling frequency (Table 6.3), concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Table F.1 in Appendix F). The monthly average concentrations were multiplied by monthly average flow volumes (Table F.2) to estimate loads; monthly loads were summed to calculate an annual average methylmercury load for WY2000-2003. For all the tributaries with less frequent sampling, loads were estimated by multiplying average annual water volume for WY2000-2003 (Table 6.1) by the average wet weather methylmercury concentration for each tributary input (Table 6.3).

Methylmercury loads in Yolo Bypass outflows at Prospect Slough were evaluated for comparison to Yolo Bypass inputs and other major tributaries (e.g., the Sacramento and San Joaquin Rivers). Methylmercury concentration data for Shag Slough outflows were not available. Although sampling took place on a regular basis at Prospect Slough in the Yolo

[34] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 6.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 6.2 incorporates a small portion of the within-Delta urban runoff loading.

Bypass, only six sampling events occurred when there was net advective outflow at the Lisbon Weir (Appendix E, Section E.2.2). Dispersive or tidal flows also transport loads from the Bypass below the Lisbon Weir during almost all times; however, the actual amount is unknown at present. Therefore, annual methylmercury loading from Prospect Slough was estimated by multiplying average methylmercury concentrations observed when the slough had net outflow (0.346 ng/l) by the annual average net advective outflow from the Yolo Bypass (1.0 M acre-ft/yr for WY2000-2003, see Appendix E, Section E.2.2).

The resulting Yolo Bypass load (443 g/yr) is comparable to the sum of watershed inputs to the Yolo Bypass (440 g/yr). However, this load estimate probably underestimates export from the Bypass because, although it is based on the estimated total outflow from the Bypass, it uses methylmercury concentrations observed at Prospect Slough, and does not include outflows from Shag Slough. Recent data indicate that Shag Slough has elevated methylmercury concentrations (Foe *et al.*, 2007), possibly due to its proximity to mercury-contaminated inputs from Cache and Putah Creeks. Even so, this uncertainty is unlikely to substantially affect the load estimates for WY2000-2003, a relatively dry period (Appendix E, Section E.1). For example, the Fremont Weir and Cache Creek Settling Basin weir, the primary tributary water sources to the Yolo Bypass, did not spill at all during WY2001 (see Appendix E, Figure E.4). Foe and others (2007) found the Yolo Bypass to be a net producer of methylmercury, when conveying floodwaters. More study needs to take place to determine how much methylmercury is produced within the Yolo Bypass and how much is delivered from upstream watersheds during both wet and dry years. Central Valley Water Board staff is currently conducting such a study; final results are expected in 2008.

The Sacramento River was the primary tributary source of methylmercury (2.0 kg/yr) during WY2000-2003 (Table 6.2). LWA (2002) calculated an annual average methylmercury load of 3.2 $\pm$1.6 kg/yr for the Sacramento River at Freeport for 1980-1999 (a wetter period than the TMDL base period). Foe (2003) also concluded that the Sacramento River was the major methylmercury tributary source in all months between March 2000 and September 2001, except for March 2000 when the Yolo Bypass was flooded and it became the primary source of methylmercury. Water years 2000 through 2003 were considered normal to dry years in the Sacramento and San Joaquin watersheds. Therefore, tributary loads for the TMDL study period may underestimate long-term values. In particular, the Yolo Bypass may provide a more substantial methylmercury load to the Delta when flooded for prolonged periods, as in 1997 and 1998.

The Central Valley Water Board has conducted additional methylmercury monitoring on all major tributary inputs to the Delta and Yolo Bypass. The study will be completed and a report published in 2008.

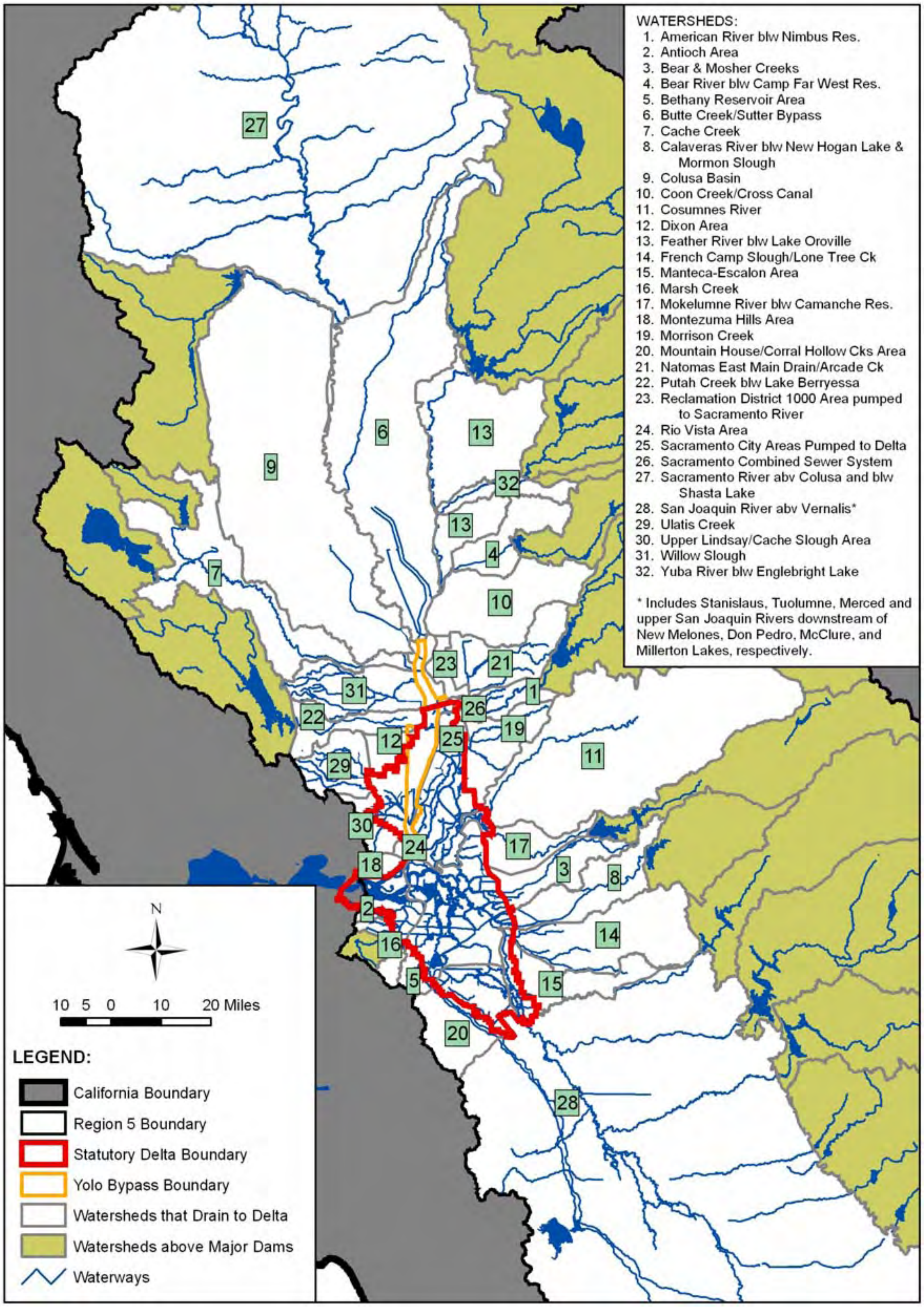

Figure 6.1: Watersheds that Drain to the Delta and Yolo Bypass.

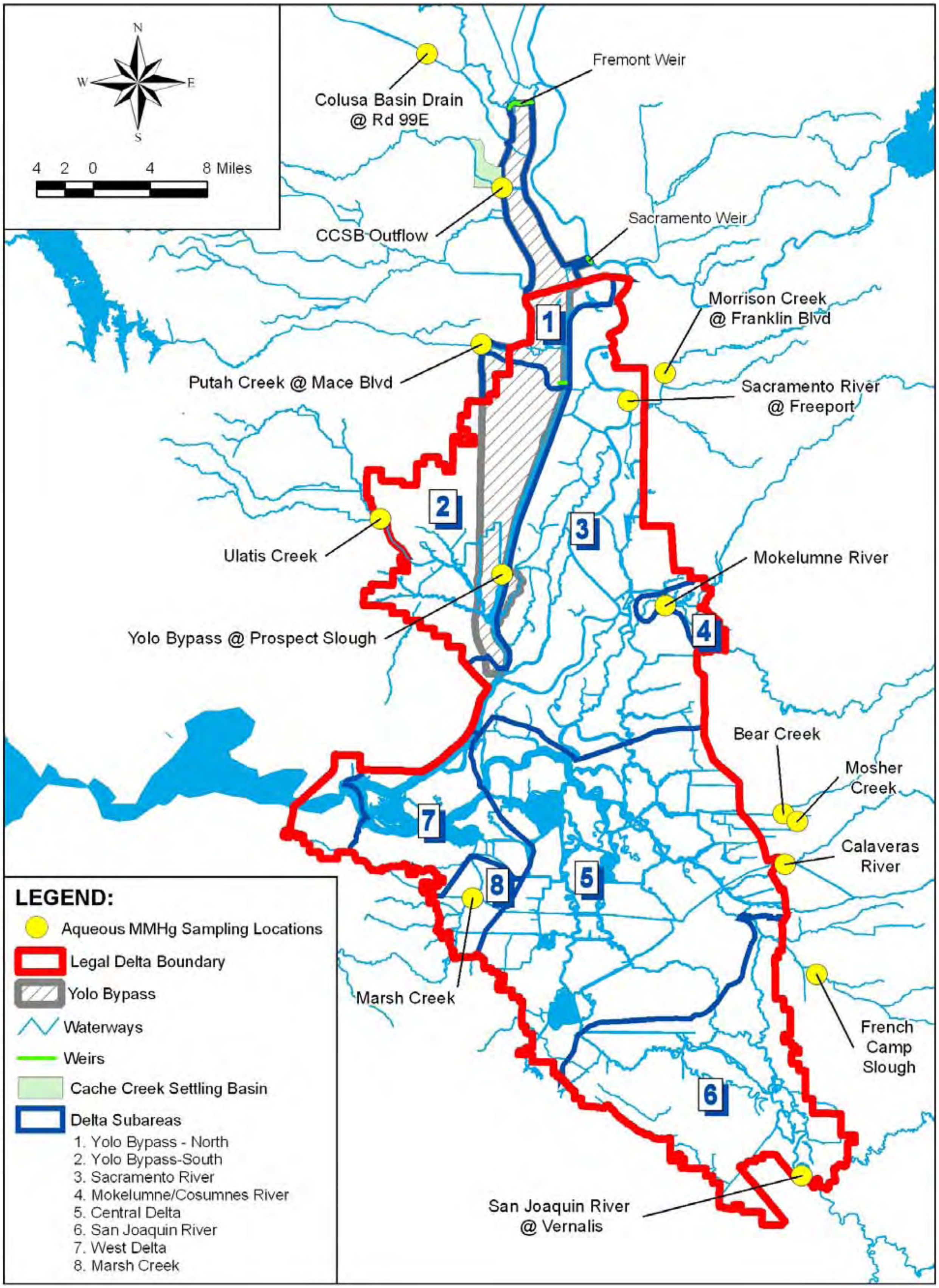

Figure 6.2: Tributary Aqueous Methylmercury Monitoring Locations

Table 6.3: Methylmercury Concentrations for Tributary Inputs.

Site [(a)]	# of Samples	Sampling Begin Date	Sampling End Date	Min. MeHg Conc. (ng/l)	Ave. MeHg Conc. (ng/l)	Annual Ave. MeHg (ng/l) [(a)]	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Large Tributaries to the Delta								
Cache Creek Settling Basin Outflow	8	3/1/2000	9/29/2003	0.155	0.504	0.504	0.432	0.991
Fremont Weir (Sacramento River @ Colusa)	30	7/20/2000	9/15/2003	0.041	0.105	0.097 (0.102) [(b)]	0.089	0.327
Knights Landing Ridge Cut (Colusa Basin Drain @ Road 99E)	21	7/21/2000	9/15/2003	0.080	0.214	0.191	0.125	0.552
Mokelumne River @ I-5	23	3/28/00	9/30/03	0.011	0.153	0.166	0.167	0.320
Putah Creek @ Mace Blvd	23	3/28/2000	9/29/2003	0.053	0.197	0.180	0.126	1.120
Prospect Slough (Yolo Bypass) [(c)]	22 (6)	3/28/00	9/30/03	0.114 (0.142)	0.256 (0.346)	0.273 (0.346)	0.209 (0.312)	0.701 (0.701)
Sacramento River @ Freeport	36	7/18/00	6/11/03	0.050	0.105	0.103	0.097	0.242
San Joaquin River @ Vernalis	31	3/28/00	4/12/04	0.093	0.156	0.160	0.147	0.256
Small Tributaries to the Delta								
Bear Creek @ West Lane	3	2/2/04	2/26/04	0.336	0.404	0.310	0.431	0.446
Calaveras River @ RR u/s West Lane	4	3/15/03	2/26/04	0.110	0.144	0.144	0.137	0.193
French Camp Slough d/s Airport Way	5	1/28/02	2/26/04	0.063	0.127	0.142	0.143	0.193
Marsh Creek @ Hwy 4	7	3/15/03	2/2/04	0.090	0.224	0.255	0.237	0.323
Morrison Creek @ Franklin	1	1/28/02	1/28/02	0.102	0.102	0.102	0.102	0.102
Mosher Creek @ Morada Lane [(d)]	1	3/15/03	3/15/03	0.028	0.028	[(d)]	0.028	0.028
Ulatis Creek near Main Prairie Rd	6	1/28/02	2/26/04	0.004	0.172	0.240	0.180	0.322

(a) For the large tributary inputs, methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads; the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The methylmercury concentration data are provided in Appendix L. The monthly average concentrations and flows are listed in Appendix F. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.2. Sampling on the small tributaries and Cache Creek Settling Basin did not take place monthly, and flow gages were unavailable for the small tributaries. All available methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads for the Cache Creek Settling Basin, and wet weather methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads for the small tributaries.

(b) The average of monthly average concentrations for Sacramento River at Colusa for months when Fremont Weir spilled during WY2000-2003 (January, February, March, May, and December) is shown in parentheses.

(c) Only six Prospect Slough MeHg sampling events took place when there was a net outflow. These sampling events are described in parentheses. Methylmercury concentrations during other times were strongly affected by tidal pumping of waters from the Sacramento River.

(d) The one Mosher Creek sample result was combined with the Bear Creek methylmercury data to estimate methylmercury loads for both creeks.

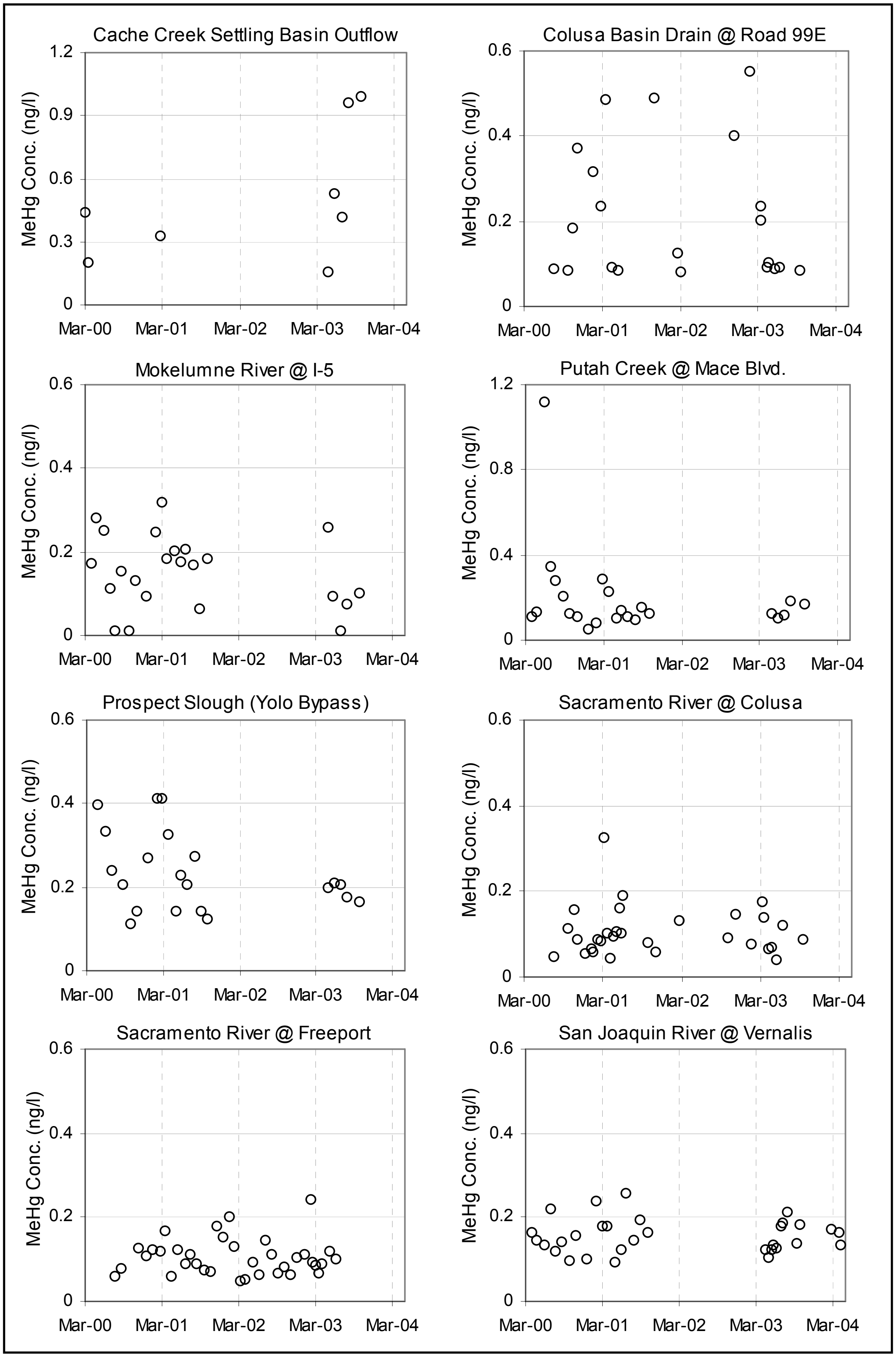

Figure 6.3a: Methylmercury Concentrations for Major Tributary Inputs

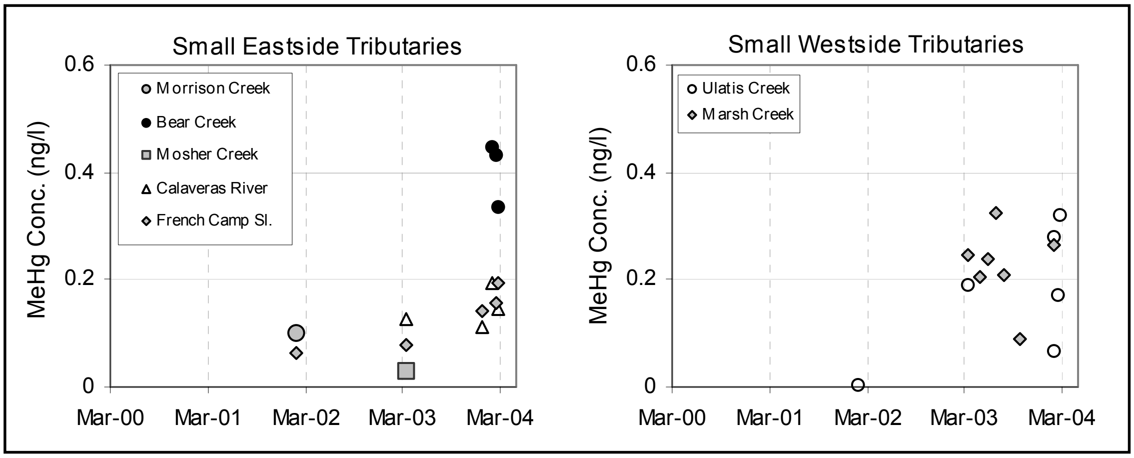

Figure 6.3b: Methylmercury Concentrations for Small Tributary Inputs

6.2.2 Within-Delta Sediment Flux

Methylmercury flux from within-Delta sediments is estimated to contribute about 36% of the overall methylmercury load (Table 6.2). Methylmercury loads from bottom sediment in open water were estimated from flux rates measured by Gill and others (2003). Wetland flux rates were from Heim, Sassone and others (Heim *et al.*, 2004; Sassone *et al.*, 2004) and a load calculation method outlined by Heim and others (Heim, 2004; Heim *et al.*, 2004). To measure methylmercury flux in open water habitats, Gill and others (2003) deployed benthic flux chambers at nine locations in the Bay-Delta region during five separate field-sampling efforts between May 2000 and October 2001. This study estimated a methylmercury flux rate of approximately 10 ng/m^2/day for open water habitat. An additional study of sediment-water MeHg flux within marsh and wetland habitat was conducted at two experimental ponds on Twitchell Island (Heim *et al.*, 2004; Sassone *et al.*, 2004). The west pond, which had more shallow water and greater coverage of emergent vegetation, had sediment-water flux rates of 41 ng/m^2/day during June 2003, while the flux from the east pond had a flux rate of 3 ng/m^2/day. In October 2003, the flux from both ponds decreased to 3 ng/m^2/day. Heim (2004) recommended that the flux rates for the west pond be used to estimate warm and cool season loads; the warm season was defined as March through September (214 days) and the cool season as October through February (151 days).

Wetland and open water acreages were estimated using the 2006 National Wetland Inventory coverage for the Delta region (USFWS, 2006; Figure 6.4). Types of wetland habitat in the Delta and Yolo Bypass are predominantly seasonal wetlands and tidal, salt, brackish and freshwater marshes. The open-water, warm season wetland and cool season wetland flux rates were multiplied by the open water and wetland areas, respectively, to estimate daily loading. The daily loads were multiplied by the number of days in the warm and cool seasons and then summed to estimate annual loading. The loads to each Delta subarea were calculated (Table 6.4) to develop subarea-specific allocations (Chapter 8). The Yolo Bypass subarea has the greatest methylmercury loading from sediment because it has the greatest acreage of wetlands; the Central Delta subarea is second because it has the greatest amount of open water habitat. Methylmercury loading from wetland and open water sediments in each subarea was summed so that the Delta-wide methylmercury loading from sediments could be compared with other sources in Table 6.2.

Using the Twitchell Island west pond summer flux rates, methylmercury loading from wetlands in the Delta/Yolo Bypass accounts for about 19% of all methylmercury to the Delta. However, if the east pond data had been used, methylmercury loading from wetlands would account for only about 3% of all methylmercury to the Delta. This illustrates the need for better characterization of wetlands throughout the Delta. Research elsewhere in California and the United States has found that wetlands are sites of efficient methylmercury production (Slotton *et al*., 2003; Heim *et al*., 2003; St. Louis *et al*., 1994, 1996; Gilmour *et al.*, 1998), so much so that one of the best predictors of methylmercury concentrations in water and in biota is the amount of wetland present in upstream watersheds (Krabbenhoft *et al.*, 1999; Wiener *et al.*, 2003b). Until additional research has been conducted in the Delta and Yolo Bypass, the Twitchell Island west pond summer flux rates will be used to estimate methylmercury loading from wetlands for the TMDL.

As described in Section 3.5, several wetland studies are underway in the Bay-Delta region. Texas A&M University, Moss Landing Marine Laboratory, CDFG and Central Valley Water Board are conducting additional loading studies to better define methylmercury sediment flux rates from different types of wetlands, open water, floodplain and other habitats in the Delta, Yolo Bypass and their tributary watersheds. The results of these studies should be available in 2008. However, additional studies will be needed to evaluate methylmercury management practices.

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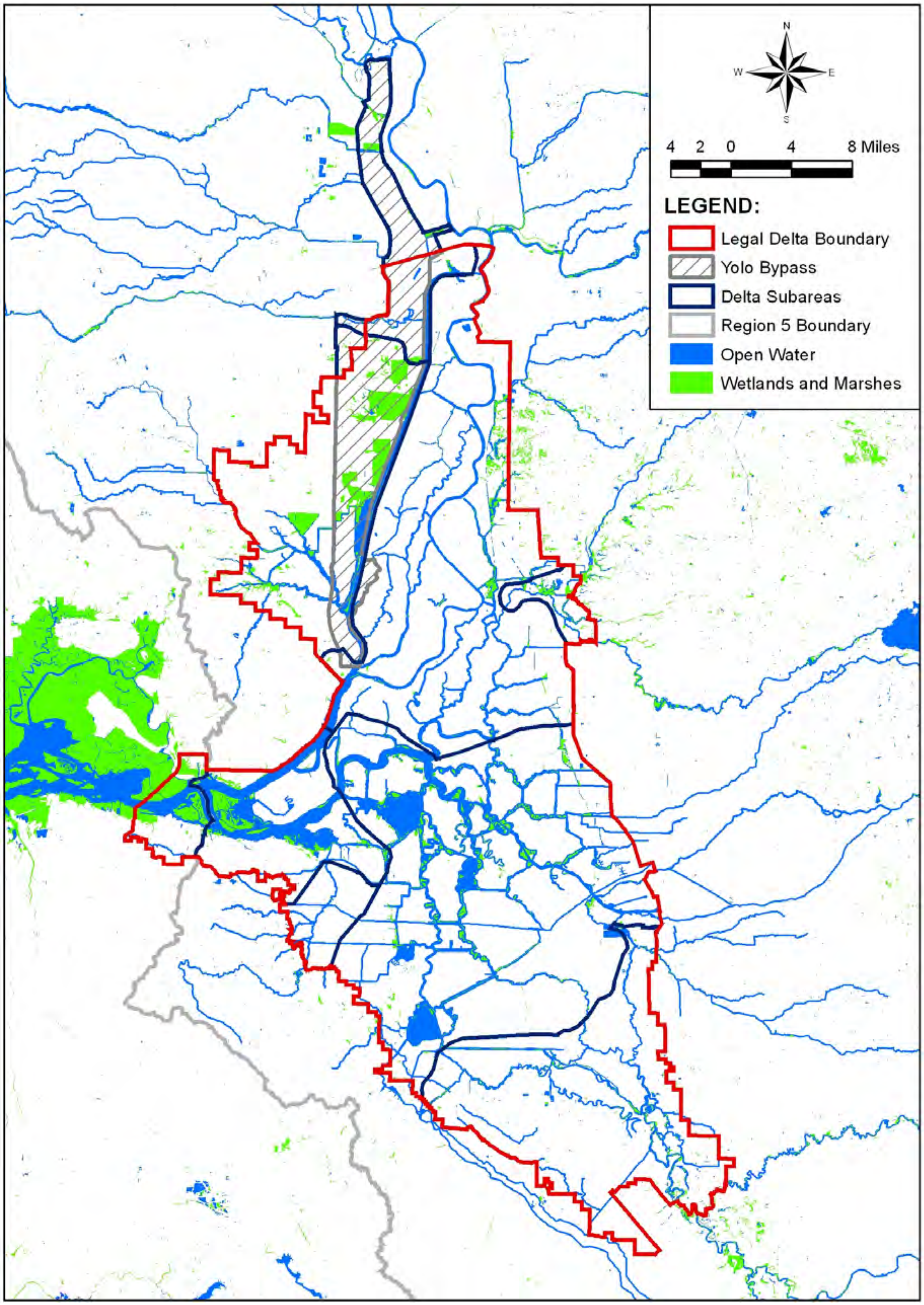

Figure 6.4: Delta and Yolo Bypass Wetlands and Open Water Habitat. Wetland areas include seasonal wetlands and brackish and freshwater marshes. (Wetland and open water acreage: USFWS, 2006.)

Table 6.4: Methylmercury Loading from Wetland and Open Water Habitats in Each Delta Subarea. [a]

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North [d]	Yolo Bypass-South	Grand Total
Open Water Habitats									
Open Water (acres):	25,141	271	12.0	9,483	3,246	13,118	1,281	5,709	58,261
% of Total Water Area:	43%	0.47%	0.02%	16%	5.6%	23%	2.2%	10%	100%
Open Water (m^2):	101,743,759	1,096,558	48,501	38,375,389	13,136,719	53,088,806	5,185,613	23,102,662	235,778,006
Daily Open Water MeHg Load (g/day) [b]:	1.02	0.0110	0.0005	0.38	0.13	0.53	0.052	0.23	2.4
Annual Open Water MeHg Load (g/year):	371	4.0	0.18	140	48	194	19	84	861
Wetland Habitats [c]									
Wetland Area (acres):	5,594	803	9.2	2,538	1,170	3,609	1,577	11,276	26,576
% of Total Wetland Area:	21%	3.0%	0.03%	9.6%	4.4%	14%	5.9%	42%	100%
Wetland Area (m^2):	22,636,361	3,250,048	37,399	10,272,237	4,735,497	14,605,419	6,382,048	45,632,423	107,551,433
Warm Season MeHg Daily Load (g/day):	0.92	0.13	0.0015	0.42	0.19	0.59	0.26	1.9	4.4
Cool Season MeHg Daily Load (g/day):	0.068	0.010	0.00011	0.031	0.014	0.044	0.019	0.14	0.32
Annual Wetland MeHg Load (g/year):	207	29.7	0.34	94	43	134	58	417	983
Annual MeHg Load (grams/year):	**578**	**34**	**0.52**	**234**	**91**	**327**	**77**	**501**	**1,844**

(a) Wetland and open water habitat acreages were obtained from the National Wetland Inventory (USFWS, 2006).

(b) The daily open water MeHg load for each Delta subarea was estimated by multiplying its open water area by the open water sediment flux rate, 10 ng/m2/day. The open water MeHg flux rate was developed by Gill and others using benthic flux chambers (Gill *et al.*, 2003).

(c) The daily warm season and cool season wetland MeHg loads for each Delta subarea were estimated by multiplying the open water area by the warm and cool season wetland flux rates, 41 ng/m2/day and 3 ng/m2/day. The warm and cool season wetland flux rates were developed by Heim and others (2004) using direct measurement of MeHg concentrations in inflows and outflows from test wetlands on Twitchell Island in the west Delta. The warm season for the wetland flux rate is defined approximately as March through September (214 days) and the cool season is defined approximately as October through February (151 days) (Heim, 2004). The annual load was estimated by multiplying the number of days in the warm and cool seasons by the daily warm and cool season loads, respectively, and summing the resulting seasonal loads.

(d) The Yolo Bypass-North subarea includes wetland and open water areas in the Yolo Bypass north of the legal Delta boundary.

6.2.3 Municipal & Industrial Sources

Twenty-one NPDES-permitted municipal and industrial dischargers are located in the Delta (Figure 6.5, Table 6.5). These facility discharges account for about 4% (204 g/yr) of the annual methylmercury loading to the Delta (Table 6.2). Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database. Information on average discharge rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits.

As described in Sections 6.2.1 and 6.3.1, the WY2000-2003 period encompasses the available methylmercury concentration data for the major Delta tributary inputs and exports. However, only one NPDES-permitted discharger collected effluent methylmercury data during this period. Between December 2000 and June 2003, the Sacramento Regional County Sanitation District (SRCSD) collected 60 samples to characterize its effluent methylmercury levels. In February and March 2004, Central Valley Water Board staff conducted two sampling events at four municipal wastewater treatment plants (WWTPs) to determine whether the SRCSD data are representative of other municipal wastewater treatment plants' effluent methylmercury levels. The 2004 sampling results indicated that the methylmercury data from the SRCSD facility may not be representative of other facilities in the Delta region. Therefore, the Central Valley Water Board issued a California Water Code Section 13267 order in July 2004 requiring municipal WWTPs and other dischargers located in the Delta and downstream of major dams in the Delta's tributary watersheds to monitor and characterize their effluent. Table 6.5 summarizes the results of available methylmercury data for facility discharges in the Delta. Table G.3 in Appendix G provides a summary of the methylmercury data generated by NPDES facility sampling efforts throughout the Delta region. A detailed review of the data is provided in the Central Valley Water Board staff report, *A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley* (Bosworth *et al.*, 2008), along with a copy of the letter and a list of facilities that received the Section 13267 order and a summary of all available methylmercury data for facility discharges to the Delta and its tributary watersheds. Appendix L of this report provides the available data for facilities within the legal Delta boundary and Yolo Bypass.

Fifteen of the facilities in the Delta/Yolo Bypass are municipal wastewater treatment plants. Average annual methylmercury load for SRCSD's Sacramento River WWTP was calculated using the average effluent methylmercury concentrations observed between December 2000 and June 2003 and the average annual discharge volume for WY2001-2003 (October 2000 through September 2003). Average annual methylmercury loads were calculated for all other municipal WWTPs using the average effluent methylmercury concentrations based on available data collected between August 2004 and October 2005 and the annual discharge volume for WY2005 (October 2004 through September 2005). Facility-specific average effluent methylmercury concentrations ranged from less than 0.02 ng/l (Brentwood and Deuel Vocational Institute WWTPS) to 2.2 ng/l (SRCSD Walnut Grove WWTP).

The variability in the methylmercury concentrations observed in effluent from different municipal WWTPs in the Delta is comparable to WWTP effluent concentrations observed elsewhere. Sampling at the San Jose/Santa Clara Water Pollution Control Plant in California indicated an average effluent methylmercury concentration of 0.04 ng/l (SJ/SC, 2007). A study that evaluated methylmercury concentrations in three domestic sewage treatment plants at the City of Winnipeg, Canada, found average effluent methylmercury concentrations to be very low at two facilities (0.13 to 0.56 ng/l, no seasonal trend) and higher at a third (greater than 2 ng/l, with highest concentrations in the summer) (Bodaly *et al*., 1998). A separate study that evaluated seasonal patterns in sewers and wastewater unit processes in the Onondaga County Metropolitan Wastewater Treatment Plant in Syracuse, New York, observed a mean methylmercury concentration (± standard deviation) of 1.63 ± 1.19 and 1.43 ± 0.67 ng/l in warm and cool months, respectively; a peak of 3.70 ng/l was measured in May (McAlear, 1996). Additional information about facilities elsewhere in California and the United States is provided in "*A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley*" (Bosworth *et al.*, 2008).

Some type of seasonal or other treatment-related variability was observed in effluent methylmercury concentrations at several of the municipal WWTPS in the Delta and its tributary watersheds (Bosworth *et al.*, 2008). Identifying the reasons why some facilities discharge effluent with higher methylmercury concentrations than others, and why some facilities have seasonal or other treatment-related variability in their methylmercury discharges, could be critical components to the development of methylmercury controls.[35]

The City of Sacramento owns and operates a combined sewer system (CSS) that serves about eleven thousand acres. The CSS conveys up to 60 mgd of domestic and industrial wastewater and storm runoff to the SRCSD's Sacramento River WWTP. The City of Sacramento operates its Combined Wastewater Treatment Plant (CA0079111) only when combined wastewater/storm flows exceed 60 mgd (Table G.2 in Appendix G). The plant provides primary treatment with disinfection. The CSS discharges to receiving waters only when storm flows exceed total treatment and storage capacity. Discharges are predominantly urban storm runoff. No methylmercury data are available yet for the plant or untreated CSS discharges. Therefore, the average methylmercury concentration in wet weather urban runoff (0.241 ng/l, see Section 6.2.5) and average annual discharge volume (467 million gallons/year, see Table G.2b) were used to estimate a CSS methylmercury load of 0.43 g/yr.

The Oakwood Lake Subdivision Mining Reclamation (CA0082783; formerly known as the Manteca Aggregate Sand Plant) allows flood-control pumping from Oakwood Lake, a former excavation pit filled primarily by groundwater, to the San Joaquin River. The results from

[35] In addition, seasonal increases in effluent methylmercury loading from some facilities could result in a greater influence on local water bodies, especially during the dry season. For example, SRCSD Sacramento River WWTP (the largest permitted facility discharge in the Central Valley) has an annual effluent methylmercury load (161 g/yr, see Table 6.5) that averages about 8% of its receiving water load (2,026 g/yr, Sacramento River at Freeport, see Table 6.2). Between December 2000 and September 2003 (the TMDL Period), SRCSD daily effluent loads during the wet seasons (e.g., December to April) ranged between 1 and 7% of river loads, and daily effluent volumes averaged about 2% of river volume (Bosworth *et al.*, 2008). However, during the dry season, SRCSD daily effluent loads ranged between about 10 and 35% of river loads while effluent volume remained about 2% of river volume. Currently, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, this TMDL is based on annual average source loads to weight all seasons equally. However, studies are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain; results from these studies may lead to future revisions in the TMDL. Seasonal discharge information is not yet available for most methylmercury sources to the Delta, but would be required by the source control and characterization studies proposed by the draft implementation plan described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.

discharge sampling in August and November 2004, nondetect (<0.02 ng/l) and 0.043 ng/l respectively, are comparable to groundwater treatment plant discharges in the Delta's tributary watersheds (refer to Table G.3 in Appendix G) and are substantially lower than the monthly average methylmercury concentrations observed in the San Joaquin River at Vernalis between August and December (0.102 to 0.167; refer to Table F.1 in Appendix F). Average annual methylmercury loading from Oakwood Lake was estimated using a methylmercury concentration of 0.03 ng/l and the average annual discharge volume.

Three of the facilities in the Delta are power or heating/cooling facilities: GWF Power Systems (CA0082309), Mirant Delta LLC Contra Costa Power Plant (CA0004863), and the State of California Central Heating/Cooling Plant (CA0078581). Two of these facilities use ambient water for cooling water. Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G and Bosworth *et al.*, 2008), such facilities do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available (see Section 7.1.2). GWF Power Systems (CA0082309) acquires its intake water from sources other than ambient surface water; adequate data were available to estimate the methylmercury load in its discharge.

The Metropolitan Stevedore Company (CA0084174) operates a marine bulk commodity terminal on leased land at the Port of Stockton. Storm water runoff, dust suppression water, and wash down water from bulk materials handling operations collect in a primary retention basin and some other low areas onsite, and evaporate or percolate into groundwater. Discharges may occur during intense storm events or when annual accumulated rainfall far exceeds the average for a given year. Methylmercury concentrations and loads in non-storm water discharges will be evaluated once the Metropolitan Stevedore Company completes methylmercury monitoring.

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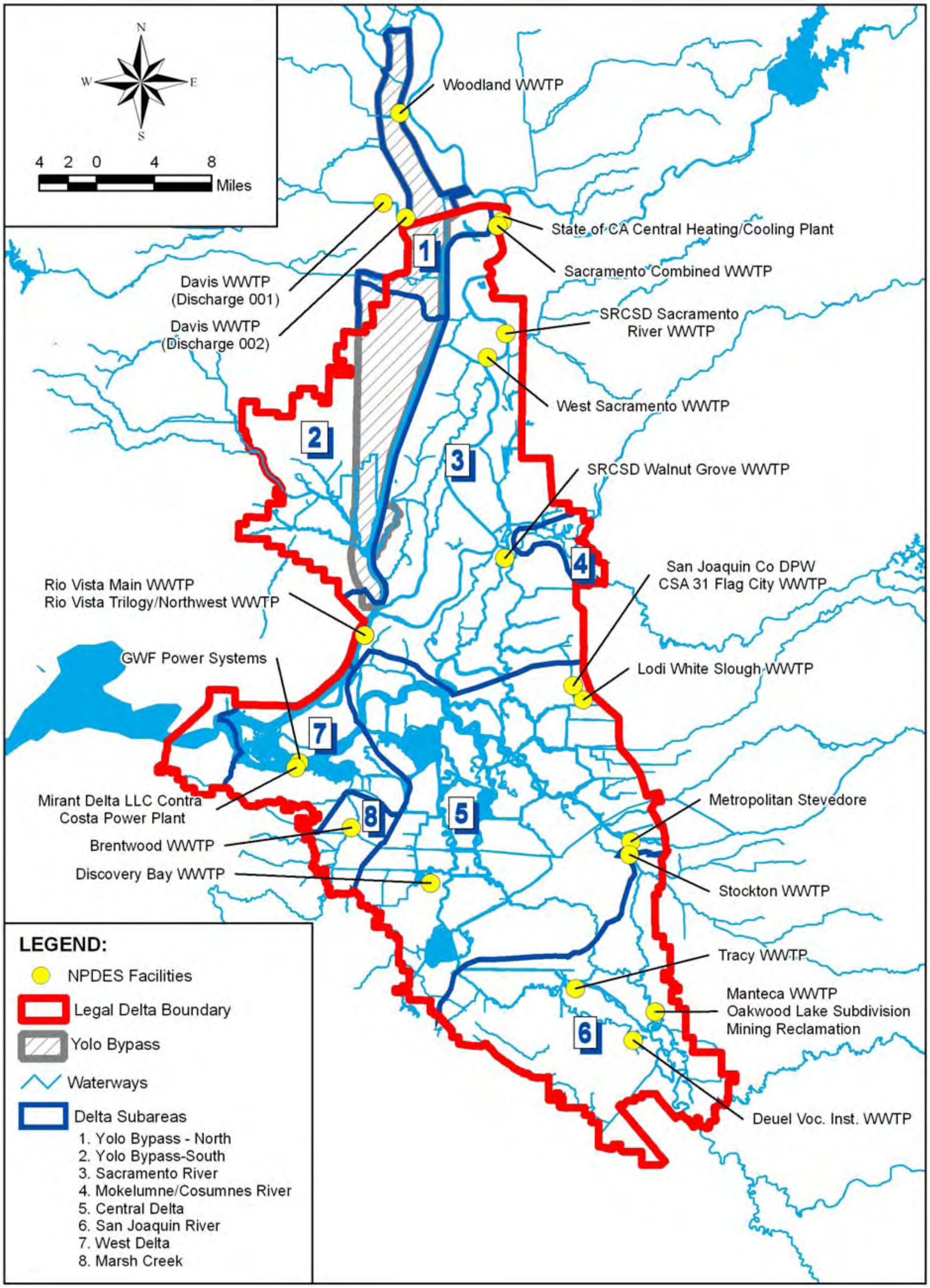

Figure 6.5: NPDES Facilities that Discharge to the Statutory Delta Boundary and Yolo Bypass.

Table 6.5: Summary of Unfiltered Methylmercury Concentration Data for Effluent from NPDES-permitted Facilities That Discharge to the Delta and Yolo Bypass North of the Delta.

Facility Name [(a)]	NPDES #	Facility Type	Delta Subarea	# of MeHg Sampling Events	Average MeHg Conc. (ng/l) [(b)]	MeHg Conc. Range (ng/l)	# of Nondetect Results	MeHg Sampling Period	Average Daily Discharge for WY2005 (mgd)	Annual MeHg Load (g/yr)
Brentwood WWTP	CA0082660	Mun. WWTP	Marsh Ck	13	0.02 (ND) [(b)]	All ND [(b)]	13	8/04-8/05	3.1	0.086
Davis WWTP (Discharge 001) [(g)]	CA0079049	Mun. WWTP	Yolo Bypass	7	0.55	0.305-1.04	0	8/04-1/05, 7/05	2.8	1.3
Davis WWTP (Discharge 002) [(g)]	CA0079049	Mun. WWTP	Yolo Bypass	5	0.61	0.247-1.44	0	2/05-6/05	2.4	0.78
Deuel Vocational Institute WWTP [(e)]	CA0078093	Mun. WWTP	San Joaquin	3	0.02 (ND)	All ND	3	1/05-6/05	0.47	0.013
Discovery Bay WWTP	CA0078590	Mun. WWTP	Central	13	0.18	ND-2.03	8	8/04-8/05	1.5	0.37
GWF Power Systems	CA0082309	Power	West	4	0.03 (ND)	All ND	4	8/04-5/05	0.05	0.0019
Lodi White Slough WWTP [(f)]	CA0079243	Mun. WWTP	Central	10	0.15	ND-1.24	3	9/04-6/05	4.5	0.93
Manteca WWTP	CA0081558	Mun. WWTP	San Joaquin	11	0.22	0.037-0.356	0	9/04-7/05	4.6	1.4
Mirant Delta LLC Contra Costa Power Plant (Outfall 1)	CA0004863	Power	West	12	0.07	ND-0.121	1	2/04-5/05	2.90	[(c)]
Mirant Delta LLC Contra Costa Power Plant (Outfall 2)	CA0004863	Power	West	10	0.09	0.042-0.15	0	2/04-3/05	121.03	[(c)]
Oakwood Lake Subdivision Mining Reclamation [(d)]	CA0082783	Lake Dewatering	San Joaquin	2	0.03	ND-0.043	1	8/04-11/04	9.15	0.38
Rio Vista WWTP	CA0079588	Mun. WWTP	Sacramento	4	0.16	0.035-0.522	0	8/04-4/05	0.47	0.10
Rio Vista Trilogy/Northwest WWTP [(i)]	CA0083771	Mun. WWTP	Sacramento						0.10 / 1.0	[(i)]
San Joaquin Co DPW CSA 31 Flag City WWTP	CA0082848	Mun. WWTP	Central	3	0.08	ND-0.152	1	1/05-10/05	0.06	0.0066
SRCSD Sacramento River WWTP	CA0077682	Mun. WWTP	Sacramento	60	0.72	0.118-1.64 [(h)]	0	12/00-6/03	162 [(h)]	161
SRCSD Walnut Grove WWTP [(e)]	CA0078794	Mun. WWTP	Sacramento	2	2.2	0.949-3.36	0	1/05-4/05	0.08	0.24
State of California Central Heating/Cooling Plant	CA0078581	Heating /Cooling	Sacramento	4	0.01	ND-0.029	3	8/04-6/05	5.26	[(c)]
Stockton WWTP	CA0079138	Mun. WWTP	San Joaquin	12	0.94	ND-2.09	1	8/04-7/05	28	36
Tracy WWTP	CA0079154	Mun. WWTP	San Joaquin	13	0.14	ND-0.422	1	8/04-8/05	9.5	1.8
West Sacramento WWTP	CA0079171	Mun. WWTP	Sacramento	12	0.05	ND-0.085	1	8/04-7/05	5.6	0.39
Woodland WWTP	CA0077950	Mun. WWTP	Yolo Bypass	12	0.03	ND-0.059	2	8/04-7/05	6.05	0.25

Table 6.5 Footnotes:

(a) No methylmercury data are yet available for Metropolitan Stevedore (CA0084174), a marine bulk commodity terminal in the Central Delta subarea, and the Sacramento Combined WWTP (CA0079111) in the Sacramento River subarea.

(b) ND: nondetect (below method detection limit). Analytical method detection limits were 0.025 ng/l or less. One half the detection limit was used for nondetect values to calculate the average methylmercury concentrations and loads, except when a facility reported all nondetect values ("All ND"), in which case the detection limit was used to calculate loads.

(c) Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), power and heating/cooling facilities that use ambient water for cooling water do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

(d) The Oakwood Lake Subdivision Mining Reclamation was formerly known as the Manteca Aggregate Sand Plant.

(e) Results for the following facilities and sample dates were not incorporated in the summary calculations due to sample preservation hold times exceeding USEPA recommendations: Deuel Vocational Institute WWTP (26 October 2004, <MDL) and SRCSD Walnut Grove WWTP (29 December 2004, 0.759 ng/l).

(f) Lodi White Slough WWTP sampled effluent when discharging to land and to surface water. Only samples collected when the plant discharged to surface water (September 2004 through June 2005) were used in the summary. Effluent that was reclaimed in August 2004 and July 2005 had methylmercury concentrations of 0.054 ng/l and <0.020, respectively.

(g) The City of Davis WWTP (CA0079049) has two seasonal discharge locations; wastewater is discharged from Discharge 001 to the Willow Slough Bypass upstream of the Yolo Bypass and from Discharge 002 to the Conaway Ranch Toe Drain in the Yolo Bypass. The Discharge 001 methylmercury load is based on effluent volumes for October 2004 through January 2005 plus July 2005 through September 2005. The Discharge 002 methylmercury load is based on effluent volumes for February 2005 through June 2005.

(h) The SRCSD Sacramento River WWTP (CA0077682) methylmercury concentration data was collected between December 2000 and June 2003. Two data points failed SRCSD's Quality Assurance review (7/13/2001: 2.93 ng/l, 6/18/2006: 0.08 ng/l); these data are not included in the TMDL calculations. Average daily discharge is based on average monthly flows during WY2000-2003.

(i) The City of Rio Vista's Trilogy WWTP was replaced by the Northwest WWTP, which began discharging to the Sacramento River subarea in 2007 under the same NPDES permit (CA0083771). The Northwest WWTP has a startup dry weather discharge of 1 mgd and peak discharge of 3 mgd. No effluent methylmercury concentration data were available for either the Trilogy or Northwest WWTPs, and no effluent total mercury concentration data were available for the Northwest WWTP, at the time the Delta methylmercury TMDL was developed. The Northwest WWTP effluent methyl and total mercury loads will be determined once it completes one year of monthly monitoring of its discharge.

6.2.4 Agricultural Return Flows

More than half a million acres of the Delta islands are under agricultural production (Figure 6.6). Water seeps and is diverted onto the islands for irrigation from the surrounding river channels. The unused water is returned to Delta waterways via a series of main drains. Many of the islands are predominately peat, a substance that Gill and others (2003) and Heim and others (2003) have shown to be a good substrate for methylmercury production. Water samples collected from five Delta Island main drains in June and July 2000 suggest that the agricultural islands are net exporters of unfiltered methylmercury (Foe, 2003). Methylmercury concentrations were variable but high compared to concentrations in the river channels surrounding the islands from which the irrigation supply water was diverted and unused tail-water returned. Agricultural return flow concentrations averaged 0.35 ng/l in June and July 2000 while concentration in the supply water was 0.07 ng/l; this translates to a net production rate of approximately 17 to 35 grams per month (~0.5 to 1.1 g/day) if occurring over the entire Delta or 10 to 25% of all river loading in the two-month period (Foe, 2003).

The annual methylmercury load from agricultural lands located in the Delta was estimated to be 123 g/yr (Table 6.2). Delta agricultural diversion and return flow estimates were obtained from the Delta Island Consumptive Use Model for water year 1999, the year during which the majority of agricultural drain methylmercury data were collected (Table 6.8); these flow estimates do not include the Yolo Bypass area north of the legal Delta. The annual diversion and return flow water volumes were multiplied by their respective methylmercury concentrations to estimate annual loads. For this preliminary evaluation, the average of available agricultural drain methylmercury data (Tables 6.6 and 6.7) was used to estimate methylmercury concentrations in all Delta agricultural return flows. The methylmercury concentration of river diversions was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations between May and December (Appendix D, Table D.3). To estimate the methylmercury loading from agricultural lands, the estimated methylmercury load in the river waters diverted onto the islands was subtracted from the agricultural return loads (Table 6.6), resulting in a net input of 123 grams per year. This load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate a subarea specific loading rate (Table 6.9). The Central Delta and Sacramento River subareas have the greatest estimated methylmercury loading from agricultural lands because they have the largest acreage of agricultural land.

This evaluation indicates that agricultural runoff within the Delta and Yolo Bypass may contribute about 2.4% of the methylmercury load to the Delta/Yolo Bypass. However, Central Valley Water Board staff recognizes that agricultural loads have not been fully characterized. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize loads from the Delta Islands and upland areas within and upstream of the legal Delta and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta region.

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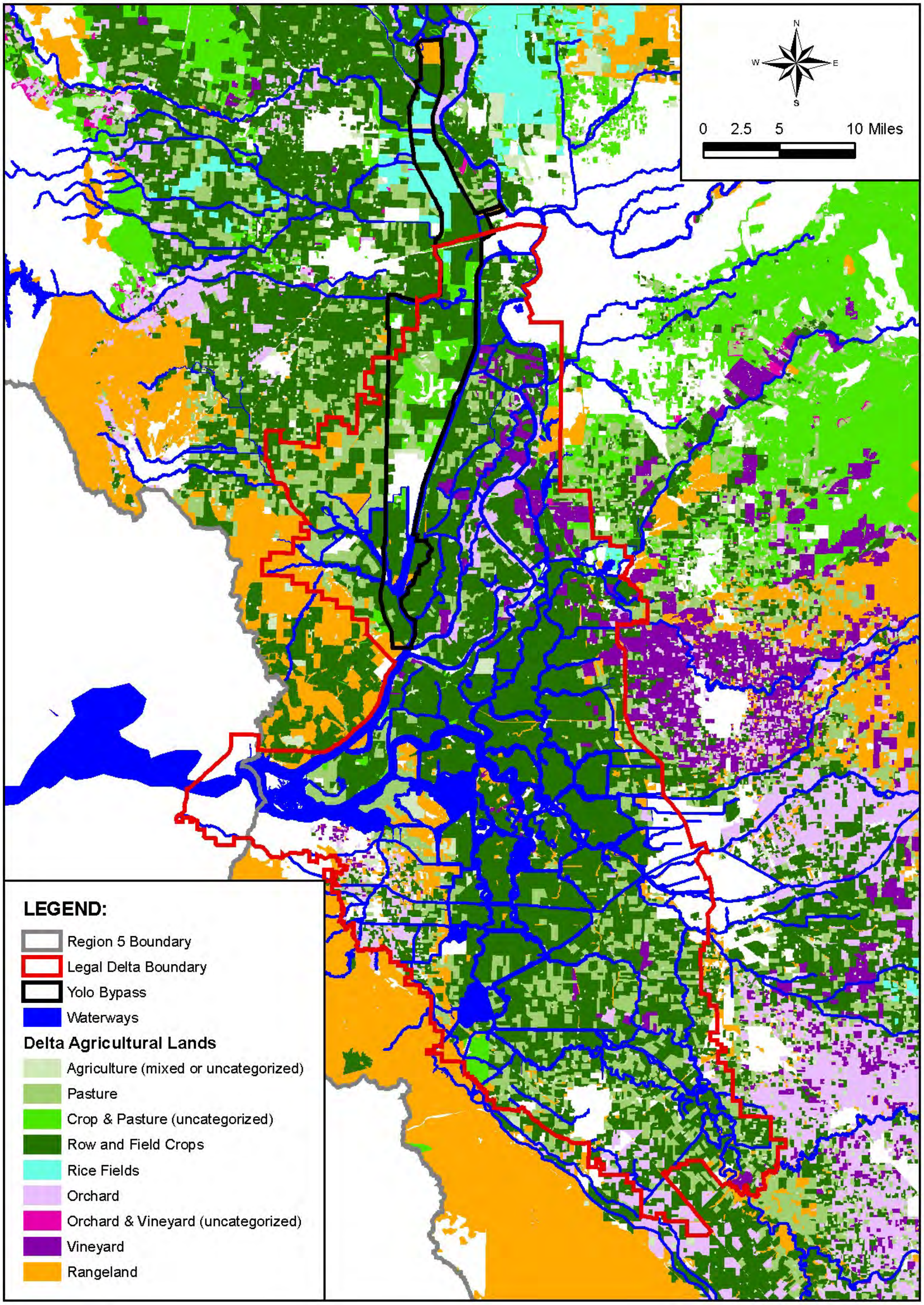

Figure 6.6: Agricultural Lands within the Statutory Delta Boundary and Yolo Bypass.

Table 6.6: Values Used to Estimate MeHg Loads from Agricultural Lands within the Legal Delta Boundary

	Average MeHg Conc. (ng/l) [a]	Flow (acre-feet/yr) [b]	MeHg Load (g/yr)
Diversions:	0.071	1,597,880	139
Ag Drain Returns:	0.352	603,546	262
Net Ag Drain Input (g/yr):			**123**

(a) Average agricultural drain methylmercury concentration obtained from Table 6.7. Average methylmercury concentration for diversion flows was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations during May through December (Appendix D).
(b) Estimated annual average agricultural diversion and return flows were obtained from Table 6.8.

Table 6.7: Delta Agricultural Main Drain Methylmercury Concentration Data [a]

Site	Sample Date	MeHg Conc. (ng/l)
Empire Tract Main Drain	6/26/00	0.093
Empire Tract Main Drain	7/19/00	0.117
Lower Jones Main Drain	6/26/00	0.302
Staten Island Main drain	6/26/00	0.198
Staten Island Main drain	7/19/00	0.094
Twitchell Island Main Drain	6/26/00	0.387
Twitchell Island Main Drain	7/19/00	1.500
Twitchell Island Main Drain	6/30/03	0.292 [b]
Twitchell Island Main Drain	7/28/03	0.341
Twitchell Island Main Drain	8/27/03	0.609
Twitchell Island Main Drain	9/25/03	0.157 [b]
Upper Jones Main Drain	7/19/00	0.131

(a) Source: Foe, 2003; Central Valley Water Board sampling, 2003.
(b) Average of laboratory replicates (0.289 and 0.294 ng/l on 6/30/03 and 0.147 and 0.167 ng/l on 9/25/03).

Table 6.8: Delta-wide Island Consumptive Use Estimates – Water Year 1999 (acre-feet)

Period [a]	Diversions + Seepage	Return Flow	Net Channel Depletion
Oct-98	92,969	36,155	56,815
Nov-98	74,202	34,988	39,213
Dec-98	81,348	31,359	49,989
Jan-99 [b]	*42,180*	*111,661*	*-69,481*
Feb-99 [b]	*34,044*	*120,960*	*-86,916*
Mar-99	57,306	43,410	13,896
Apr-99	108,000	46,532	61,468
May-99	193,317	67,944	125,373
Jun-99	273,838	92,648	181,190
Jul-99	353,800	120,147	233,653
Aug-99	221,540	77,167	144,373
Sep-99	141,560	53,197	88,364
Annual Totals [b]	**1,597,880**	**603,546**	**994,334**

(a) Diversion and return flow volumes were obtained from the Delta Island Consumptive Use Model (Suits, 2000).
(b) Only months with positive depletion were used in the annual methylmercury load estimates because no methylmercury concentration data were available for the agricultural return drains during the coolest/wettest months.

Table 6.9: Agricultural Acreage and Methylmercury Load Estimates by Delta Subarea

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North [c]	Yolo Bypass-South	**TOTAL**
Acreage [a]	157,035	6,790	9,362	155,532	96,874	17,313	11,046	70,523	**524,474**
% of Total Acreage	30%	1.3%	1.8%	30%	18%	3.3%	2.1%	13%	**100%**
Estimated Annual MeHg Load (g/year) [b]	36.8	1.6	2.2	36.4	22.7	4.1	2.6	16.5	**123**

(a) Land cover source: DWR land use GIS coverages (1993-2003).
(b) A Delta-wide agricultural land methylmercury loading of 123 g/yr was estimated using the information presented in Tables 6.6 through 6.8. The Delta-wide load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate the amount of loading from agricultural lands in each subarea.
(c) The Yolo Bypass-North subarea does not include agricultural areas in the Yolo Bypass north of the legal Delta boundary.

6.2.5 Urban Runoff

Approximately 60,000 acres of the land in the Delta and Yolo Bypass north of the legal Delta boundary is classified as urban (DWR, 1993-2003). Most of the urban area is regulated by waste discharge requirements under the National Pollutant Discharge Elimination System (NPDES), which permits discharge of storm water from municipal separate storm sewer systems (MS4s). [36] Table 6.10 lists the permits that regulate urban runoff in the Delta and the amount of urban acreage in each Delta subarea. Figure 6.7 shows their locations. Urban acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available MS4 service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city and county boundaries. Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category within each Delta subarea.

Methylmercury concentration data have been collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways in or adjacent to the Delta. Figure 6.8 shows the sampling locations, Figure H.1 in Appendix H illustrates the wet and dry weather concentrations by location, and Appendix L provides the concentration data used in Figure H.1. Methylmercury concentrations ranged from a wet weather low of 0.035 ng/l (City of

[36] A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances that include roads with drainage systems, municipal streets, alleys, catch basins, curbs, gutters, ditches, manmade channels, or storm drains, owned by a State, city, county, town or other public body. MS4s are designed and used for collecting or conveying storm water and do not include combined sewer systems or parts of a publicly owned treatment works. MS4s discharge to Waters of the United States. The Municipal Storm Water Permitting Program regulates storm water discharges from MS4s. MS4 permits were issued in two phases. Under Phase I, which started in 1990, the RWQCBs have adopted NPDES storm water permits for medium (serving between 100,000 and 250,000 people) and large (serving greater than 250,000 people) municipalities. Most of these permits are issued to a group of co-permittees encompassing an entire metropolitan area. These permits are reissued as the permits expire. As part of Phase II, the State Board adopted a General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ, NPDES No. CAS000004) to provide permit coverage for smaller municipalities, including non-traditional small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

Sacramento Sump 111) to a dry weather high of 2.04 ng/l (Strong Ranch Slough). A visual inspection of the methylmercury data suggests that the differences between urban watersheds are not related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 6.11). The averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta and were used to estimate loads. These values are similar to methylmercury levels observed during high flow conditions in two urbanized tributaries in the Washington, D.C. region. The urbanized Northeast and Northwest Branches of the Anacostia River had average methylmercury concentrations of 0.12 ± 0.06 ng/l and 0.07 ± 0.07 ng/l, respectively, during base flows, and 0.39 ± 0.21 ng/l and 0.77 ± 0.46 ng/l, during high flows (Mason and Sullivan, 1998).

Average annual urban runoff loading was estimated for WY2000-2003 so that urban runoff loading could be compared to tributary loading (Table 6.2). To estimate wet weather methylmercury loads, the wet weather concentration (0.241 ng/l) was multiplied by the runoff volumes estimated for WY2000-2003 for each MS4 area within each Delta subarea. To estimate dry weather methylmercury loads, the dry weather concentration (0.363 ng/l) was multiplied by the estimated dry weather urban runoff volume. Section E.2.3 in Appendix E describes the methods used to estimate wet and dry weather runoff volumes from urban areas within the Delta. Wet and dry weather methylmercury loads were summed to estimate the average annual loading of 20 grams to Delta waterways. The loading to each Delta subarea (Table 6.12) was used to develop MS4 Permittee and subarea-specific allocations (Chapter 8).

Urban land use comprises a small portion of the surface area in the Delta and contributes only about 0.4% of the Delta methylmercury load (Table 6.2). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – occur within 20 miles of the statutory Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta load estimate. As a result, the urban contribution to the Delta methylmercury load may be underestimated.

To evaluate the potential contributions from upstream urban lands, the methylmercury loadings from the two MS4 service areas with the greatest urban acreage immediately upstream of the Delta were estimated. The sum of methylmercury loads from the Sacramento and Stockton MS4 areas may contribute about 1% of methylmercury loading to the Delta (Table 6.13). These loads are expected to increase as urbanization continues around the Delta.

Table 6.10: Urban Acreage and MS4 Permits that Regulate Urban Runoff within the Delta/Yolo Bypass.

Permittee	**NPDES #** [(a)]	**Urban Acreage within Delta Subareas** [(b)] Central Delta	Marsh Creek	Mokelumne / Cosumnes Rivers	Sacra-mento River	San Joaquin River	West Delta	Yolo Bypass [(c)]	**Total Acreage**
Contra Costa County	CAS083313	2,181	3,427				9,518		15,126
Lathrop (City of)	CAS000004					738			738
Lodi (City of)	CAS000004	134							134
Port of Stockton	CAS084077	1,067				28			1,095
Rio Vista (City of)	CAS000004				37				37
Sacramento Area MS4 [(d)]	CAS082597				4,766				4,766
San Joaquin County	CAS000004	1,494		121	521	6,040			8,176
Solano County	CAS000004				181			220	401
Stockton MS4 Permit Area	CAS083470	10,574				1,481			12,055
Tracy (City of)	CAS000004					5,268			5,268
West Sacramento (City of)	CAS000004				1,824			2,756	4,580
Yolo County	CAS000004				200			796	966
Urban Nonpoint Source [(e)]		337		44	1,615	7	231		2,234
Total Acreage		**15,787**	**3,427**	**165**	**9,144**	**13,562**	**9,749**	**3,772**	**55,606**

(a) Permittees with NPDES No. CAS000004 are covered under the General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ) adopted by the State Water Board to provide permit coverage for smaller municipalities (serving less than 100,000 people).

(b) Urban land uses and acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city boundaries.

(c) The Yolo Bypass subarea includes urban areas in the Yolo Bypass north of the legal Delta boundary.

(d) The Sacramento MS4 Area does not include the Sacramento Combined Sewer System (CSS) service area illustrated in Figure 6.7. The CSS service area is permitted by a separate NPDES permit, which is described in Section 6.2.3 and Table G.2 in Appendix G.

(e) Urban areas not encompassed by a MS4 service area were grouped into the “nonpoint source” category.

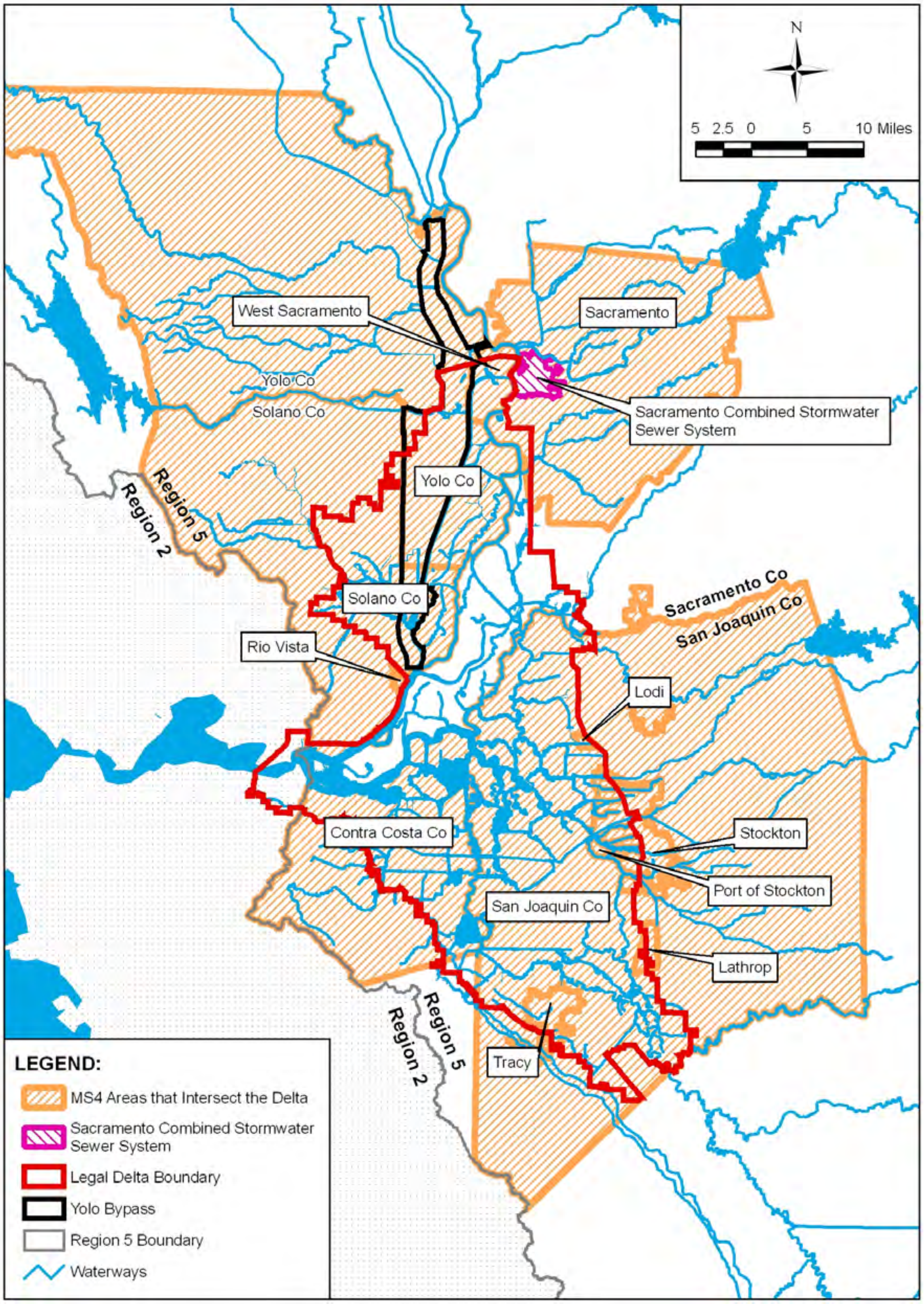

Figure 6.7: NPDES Permitted Municipal Separate Storm Sewer System (MS4) Areas in the Delta Region. (Only those MS4 areas that intersect the statutory Delta boundary and Yolo Bypass are labeled. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city or county boundaries.)

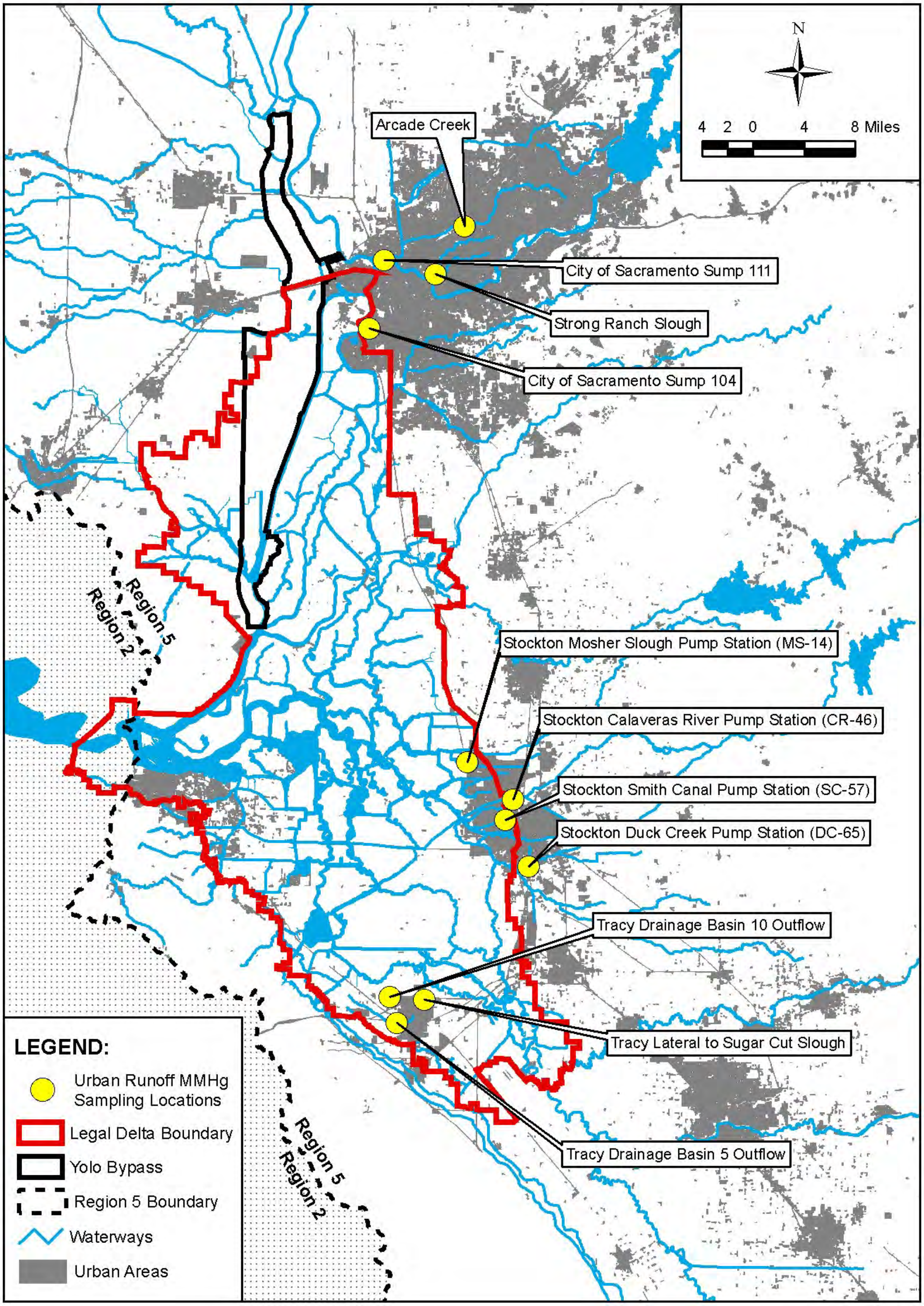

Figure 6.8: Urban Areas and Aqueous MeHg Sampling Locations in the Delta Region.

Table 6.11: Summary of Urban Runoff Methylmercury Concentrations

Location	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
DRY WEATHER				
Arcade Creek	9	0.099	0.358	1.213
Sacramento Strong Ranch Slough	2	0.158	1.099	2.040
Sacramento Sump 104	2	0.088	0.093	0.097
Sacramento Sump 111	2	0.135	0.176	0.217
Tracy Lateral to Sugar Cut Slough	1	0.091	0.091	0.091
Average of Location Averages:	**0.363 ng/l**			
WET WEATHER				
Arcade Creek	7	0.099	0.240	0.339
Sacramento Strong Ranch Slough	4	0.237	0.522	0.878
Sump 104	4	0.153	0.290	0.610
Sump 111	4	0.035	0.212	0.420
Stockton Calaveras River Pump Station	5	0.105	0.167	0.301
Stockton Duck Creek Pump Station	1	0.103	0.103	0.103
Stockton Mosher Slough Pump Station	4	0.084	0.125	0.189
Stockton Smith Canal Pump Station	4	0.099	0.263	0.533
Tracy Drainage Basin 10 Outflow	3	0.103	0.192	0.257
Tracy Drainage Basin 5 Outflow	3	0.110	0.138	0.191
Tracy Lateral to Sugar Cut Slough	3	0.040	0.400	0.918
Average of Location Averages:	**0.241 ng/l**			

Table 6.12: Average Annual Methylmercury Loading from Urban Areas within Each Delta Subarea for WY2000-2003

MS4 PERMITEE	DELTA SUBAREA (g/yr)							Grand Total (g/yr)
	Central Delta	Marsh Creek	Mokelumne / Cosumnes Rivers	Sacra-mento River	San Joaquin River	West Delta	Yolo Bypass	
Contra Costa County	0.75	1.2				3.2		**5.2**
Lathrop (City of)					0.27			**0.27**
Lodi (City of)	0.053							**0.053**
Port of Stockton	0.39				0.010			**0.40**
Rio Vista (City of)				0.014				**0.014**
Sacramento Area MS4				1.8				**1.8**
San Joaquin County	0.57		0.045	0.19	2.2			**3.0**
Solano County				0.073			0.085	**0.16**
Stockton MS4 Permit Area	3.6				0.50			**4.1**
Tracy (City of)					1.8			**1.8**
West Sacramento (City of)				0.65			1.1	**1.8**
Yolo County				0.073			0.33	**0.40**
Urban Nonpoint Source	0.14		0.018	0.63	0.0022	0.066		**0.85**
Grand Total	**5.5**	**1.2**	**0.063**	**3.4**	**4.8**	**3.3**	**1.5**	**20**

Table 6.13: Comparison of Sacramento and Stockton Area MS4 Methylmercury Loading to Delta Methylmercury Loading for WY2000-2003.

MS4 Service Area [(a)]	Water Volume (M acre-feet) [(b)]	MeHg Load (grams/year)
Sacramento MS4 Urban Total	0.18	59
Stockton MS4 Urban Total	0.026	8.6
Total Delta Inputs [(c)]	20	5,219
Stockton & Sacramento Runoff as % of Total Delta Inputs	**1.0%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage in the greater Delta region, with urban land use areas of about 161,000 and 25,000 acres, respectively.

(b) Refer to Section E.2.3 in Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.

(c) These values represent the sum of all tributary inputs and within-Delta methylmercury sources shown in Table 6.2.

6.2.6 Atmospheric Deposition

Atmospheric deposition of methylmercury has not yet been measured within the Delta. However, several published papers provide reviews of methylmercury levels in wet deposition in a variety of locations around the world (e.g., Nguyen *et al.*, 2005; Lawson and Mason, 2001; Mason *et al.*, 1997 and 2000). These reviews indicate that the ratios of methyl to total mercury concentrations in wet deposition range from 0.25 to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. As described in Section 7.1.4 and Table 7.1, total mercury loading from wet deposition to Delta water surfaces and land surfaces not including urban areas was estimated to be 2,318 g/yr for WY2000-2003. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited by wet deposition:

Equation 6.2:

$$\begin{aligned} \text{MeHg Mass} &= \text{Total mercury mass} * \text{MeHg:TotHg} \\ 23\text{ g/yr} &= 2.3\text{ kg/year} * 0.01 \end{aligned}$$

Table 6.14 provides the methylmercury load estimates for atmospheric deposition to each Delta subarea. Wet deposition in the Delta and Yolo Bypass likely contributes less than 1% of all methylmercury entering the Delta (Table 6.2). Therefore, it is assumed that atmospheric input to waterways and land surfaces within the Delta and Yolo Bypass is not a significant source of methylmercury. Methylmercury in wet deposition to urban land surfaces was not evaluated because it is incorporated in the estimates for loading from urbanized lands described in Section 6.2.5.

Table 6.14: Estimate of Average Annual Methylmercury Loading from Wet Deposition

Delta Subarea	WY2000-2003 Average Annual TotHg Load (g/yr) [a]	Estimated MeHg Load (g/yr) [b]
Central Delta	729	7.3
Marsh Creek	23	0.23
Mokelumne / Cosumnes River	29	0.29
Sacramento River	560	5.6
San Joaquin River	272	2.7
West Delta	237	2.4
Yolo Bypass-North [c]	100	1.0
Yolo Bypass-South	315	3.2
TOTAL	**2,265 (2.3 kg/yr)**	**23**

(a) Total mercury loading from precipitation on surface water and non-urbanized land surfaces in the Delta and Yolo Bypass was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater by the average rainfall runoff volume during WY2000-2003 (see Section 7.1.4 in Chapter 7 and Section E.2.3 in Appendix E).

(b) The published literature indicates that ratios of methyl to total mercury concentrations in wet deposition typically range from 0.25% to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited to waterways in each subarea.

(c) The Yolo Bypass-North subarea includes areas in the Yolo Bypass north of the legal Delta boundary.

6.2.7 Other Potential Sources

Potential methylmercury sources in the Delta/Yolo Bypass not evaluated by this TMDL may include the following:

- Methylmercury flux from floodplain sediments when floodplains are inundated;
- Agricultural areas in the Yolo Bypass north of the legal Delta boundary;
- Rainwater runoff from agricultural areas throughout the Delta and Yolo Bypass; and
- Runoff from rangeland and other open-space areas not encompassed by urban, wetland, or agricultural areas.

The methylmercury load estimates for methylmercury flux from open water sediments described in Section 6.2.2 do not address floodplain acreage that is not permanently inundated. As illustrated in the Sacramento-San Joaquin Delta Atlas (DWR, 1995), the Delta encompasses a maze of over 1,100 miles of river channels that are almost entirely constrained by local and Federal flood control project levees. Throughout the Delta, there is very little acreage between channel levees not already included in the wetland and open water acreages, with the exception of the Yolo Bypass. The Yolo Bypass is a massive floodplain (about 73,000 acres) on the west side of the lower Sacramento River that receives floodwaters routed from the Sacramento and Feather Rivers by the Fremont and Sacramento Weirs (see Section E.2.2 and Figure E.2 in Appendix E). The Yolo Bypass typically floods in more than half of water years, for an average of two months every other year; complete inundation of the floodplain approximately doubles the wetted area of the Delta and is equivalent to about one-third the area of San Francisco and San

Pablo bays (Sommer *et al*., 2001; Foe *et al.*, 2007). The WY2000-2003 period that encompasses the available methylmercury concentration data for the major Delta inputs and exports was a relatively dry period. However, bypass floodplain inundation may contribute methylmercury loading to the Delta. No floodplain methylmercury loading studies have been completed yet. Preliminary results from ongoing Moss Landing Marine Laboratory and Central Valley Water Board studies indicate that inundated areas in the Yolo Bypass are potentially large sources of methylmercury to the bypass and Delta (Foe, personal communication). Once these and other habitat studies are completed for a range of wet and dry years, staff will re-evaluate methylmercury loading from floodplain areas in the Yolo Bypass.

As noted in Section 6.2.4, the agricultural return flows upon which the return flow methylmercury load estimates are based do not include the Yolo Bypass area north of the legal Delta. In addition, the load estimates address only runoff during the active irrigation season because no methylmercury concentration data is available for stormwater runoff from agricultural areas. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize methylmercury loads from the agricultural areas on Delta Islands and upland areas in the Delta region and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta region.

Similarly, methylmercury concentration data were not available for stormwater runoff from rangeland and other upland areas not encompassed by urban, wetland, water, or agricultural load estimates. Because such upland areas comprise only about 8% of land cover within the Delta and Yolo Bypass, they are not expected to contribute substantially more methylmercury loading than that already present in rainfall, which was estimated for this TMDL. However, such upland areas could account for more of the methylmercury loading to tributary watersheds. Staff recommends that upstream TMDL program studies incorporate analyses of methylmercury in runoff from upland areas.

6.3 Methylmercury Losses

The following were identified as contributing to methylmercury losses from the Delta: water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, biotic uptake and unknown loss term(s). Table 6.15 lists the average methylmercury concentrations and estimated average annual loads associated with the losses for the WY2000-2003 period, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Figure 6.9 shows the aqueous monitoring locations for major methylmercury exports and the approximate locations of recent dredging projects.

Figures and tables cited in Sections 6.3.1 through 6.3.4 are arranged after Section 6.3.4 in the order in which they were mentioned.

Table 6.15: Methylmercury Concentrations and Loads Lost from the Delta for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Outflow to San Francisco Bay (X2)	1,717	69.7%	0.08
Dredging	341	13.9%	- - -
State Water Project	203	8.2%	0.05
Delta Mendota Canal	201	8.2%	0.06
Photodegradation	*To Be Determined*		
Accumulation in Biota	*Unknown*		
TOTAL EXPORTS:	**2,462 g/yr (2.5 kg/yr)**		

6.3.1 Outflow to San Francisco Bay

Outflow to San Francisco Bay is the primary way that methylmercury is lost from the Delta. Methylmercury in Delta outflow to San Francisco was evaluated by collecting samples at X2. X2 is the location in the Bay-Delta Estuary with 2 parts per thousand (o/oo) bottom salinity. The location of X2 moves as a function of both tidal cycle and freshwater inflow, typically between the Cities of Martinez and Pittsburg, west of the legal Delta boundary. This salinity was chosen because 2 to 3 o/oo salinity is the normal osmotic tolerance of freshwater organisms, and a goal of the CALFED studies was to estimate the methylmercury exposure of these organisms.

Staff from the Central Valley and San Francisco Bay Central Valley Water Boards has agreed to consider Mallard Island as the boundary between the two regions for control of mercury. The site was selected as it is near the legal boundary and has a U.S. Geological Survey flow gauge. Central Valley Water Board staff has begun collecting methylmercury concentration data at Mallard Island and will use this to better estimate advective and dispersive flux of methylmercury from the Central Valley to San Francisco Bay. The data will be collated and a report prepared in the 2008.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April to September 2003. Figure 6.10 and Table 6.16 summarize the export data. Methylmercury concentrations at X2 averaged 0.075 ng/l and ranged from below detection limits to 0.241 ng/l. Net daily Delta outflow water volumes were obtained from the Dayflow model (Section E.2.4 in Appendix E). Methylmercury concentrations for X2 and net daily Delta outflows were regressed against each other to determine whether flow could be used to predict methylmercury concentration (Appendix F). The regression was significant at $P<0.05$ and accounted for about 20% of the variation in methylmercury concentrations. The regression-based export load was 2,086 g/yr.

An alternate approach is to use average monthly methylmercury concentrations to estimate Delta exports. Concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Table F.1 in Appendix F). Monthly average concentrations were multiplied by monthly average flows for WY2000-2003 to estimate monthly loads and summed to calculate an annual average methylmercury load for WY2000-2003 of 1,717 g/yr. The latter estimate appears similar to the regression-based estimate (2,086 g/yr). Table 6.15 uses an advective export rate of 1,717 g/yr to San Francisco Bay. This accounts for approximately 70% of Delta methylmercury losses. No attempt was made to estimate dispersive loads. It is not known whether dispersive or tidal flows would increase or decrease the net methylmercury load exported to the Bay area.

6.3.2 South of Delta Exports

Water diversions to southern California account for approximately 16% of Delta methylmercury losses (Table 6.15). Methylmercury in Delta Mendota Canal (DMC) and State Water Project (SWP) exports to southern California were evaluated by collecting water samples from the DMC canal off Byron Highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta. Figure 6.9 illustrates the sampling locations.

Central Valley Water Board staff conducted monthly methylmercury sampling at the DMC and SWP from March 2000 to September 2001 (Foe, 2003) and from April 2003 to April 2004. Appendix L provides the methylmercury concentration data collected at the DMC and SWP and Figure 6.10 and Table 6.16 summarize methylmercury concentrations. The volume of water exported by the DMC and SWP was obtained from the Dayflow model (Section E.2.4 in Appendix E). Like at X2, methylmercury concentrations were regressed against daily flow to determine whether the concentrations could be predicted from the flow (Appendix F). Neither regression was significant ($P<0.05$). Therefore, average methylmercury concentrations were used to estimate SWP and DMC export loads of 203 and 201 g/yr, respectively (Table 6.15). Central Valley Water Board staff has collected additional methylmercury data at both pumping sites to better characterize methylmercury loads as part of a larger CALFED study. The study will be completed and a report published in 2008.

6.3.3 Export via Dredging

Sediment is dredged at various locations in the Delta to maintain ship channels and marinas. No data have been gathered on methylmercury levels in dredge material removed from the Delta. To determine whether dredging activities could result in notable methylmercury loss from the Delta, a preliminary load estimate was developed using available dredge volume and total mercury information and surficial sediment methylmercury concentration data. Methylmercury removed by dredge activities could account for almost 14% of the identified methylmercury exports from the Delta (Table 6.15).

Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return flow. Table 6.17 provides information for recent dredge projects within the

Delta and Figure 6.9 shows their approximate locations. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,400 cubic yards of sediment are dredged annually on average, with 199,000 cubic yards from the Sacramento Deep Water Ship Channel and 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects at marinas remove sediment at various frequencies for a combined total of about 64,400 cubic yards per year. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.41 mg/kg (dry weight). The annual mass of mercury removed from the Delta through dredging projects is approximately 57 kg/year. Section 7.2.3 provides a description of the methods used to estimate the annual mass of total mercury removed by dredging and the uncertainty in the estimate. None of the dredging projects analyzed sediment samples for methylmercury. Heim and others (2003) evaluated surficial sediment MeHg:TotHg at several locations in the Sacramento and Stockton Deep Water Channels (Table 6.18), where nearly 90% of all dredged materials from the Delta are removed. The average MeHg:TotHg of 0.006 was used to estimate the mass of methylmercury removed by dredging projects:

Equation 6.3:

$$\begin{array}{rcl} \text{MeHg Mass} & = & \text{Total mercury mass} \;*\; \text{MeHg:TotHg} \\ 341 \text{ g/yr} & = & 57 \text{ kg/year} \;*\; 1000 \text{ (g/kg)} \;*\; 0.006 \end{array}$$

Use of surficial sediment MeHg:TotHg to estimate methylmercury mass removed by dredging assumes that MeHg:TotHg is consistent throughout all depths of sediment in the dredged areas, which may overestimate the mass removed if methylmercury levels actually decrease with depth. In addition, methylmercury production may increase after dredging activities if the newly exposed sediment has higher total mercury concentrations. Central Valley Water Board staff recommends that dredgers quantify the amount of methylmercury removed and that the mercury concentration of fine grain material in newly exposed sediment be assayed (see Chapter 4 in the draft Basin Plan Amendment staff report).

6.3.4 Other Potential Loss Pathways

Accumulation by biota and photodegradation throughout the Delta have not yet been evaluated. The amount of methylmercury accumulating in aquatic biota is not known. However, studies could be undertaken to ascertain the rate of transfer from the abiotic to the biotic component of the food web. Preliminary study results for the Sacramento River near Rio Vista indicate surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' preliminary results are similar to photodegradation rates observed in Florida and Canada. Methylmercury photodegradation rates in a boreal forest lake in northwestern Ontario, Canada, ranged between -3 and 27% per day, with the highest rates at the lake surface (Sellers and Kelly, 2001). In the Everglades, Krabbenhoft and others (1999) observed methylmercury degradation rates ranging from 2 to 15% per day. Krabbenhoft and others (1999 and 2002) also found that the majority of photodegradation occurred in the top half meter of water; however, they also found that the rate of degradation was largely dependent on the concentration of dissolved organic carbon. The large surface to depth ratio of the Delta, coupled with its relatively long residence time, may result in significant loss of methylmercury by photodegradation. Byington and others' extrapolation of their preliminary study results suggests a loss of about 4 g/day over the entire Delta. Photodemethylation experiments are continuing as part of an ongoing CALFED-funded project (Proposal ERP-02-C06-B).

Table 6.16: Methylmercury Concentrations for the Delta's Major Exports

Site	# of Samples	Min. MeHg Conc. (ng/l) [(a)]	Ave. MeHg Conc. (ng/l)	Annual Ave. Conc. (ng/l) [(b)]	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Delta Mendota Canal	21	ND	0.062	0.064	0.061	0.171
State Water Project	20	ND	0.051	0.054	0.049	0.144
Outflow to San Francisco Bay (X2)	22	ND	0.075	0.083	0.070	0.241

(a) ND: below method detection limit.

(b) Sampling of these exports took place between March 2000 and September 2003. Methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Table F.1 in Appendix F); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.15.

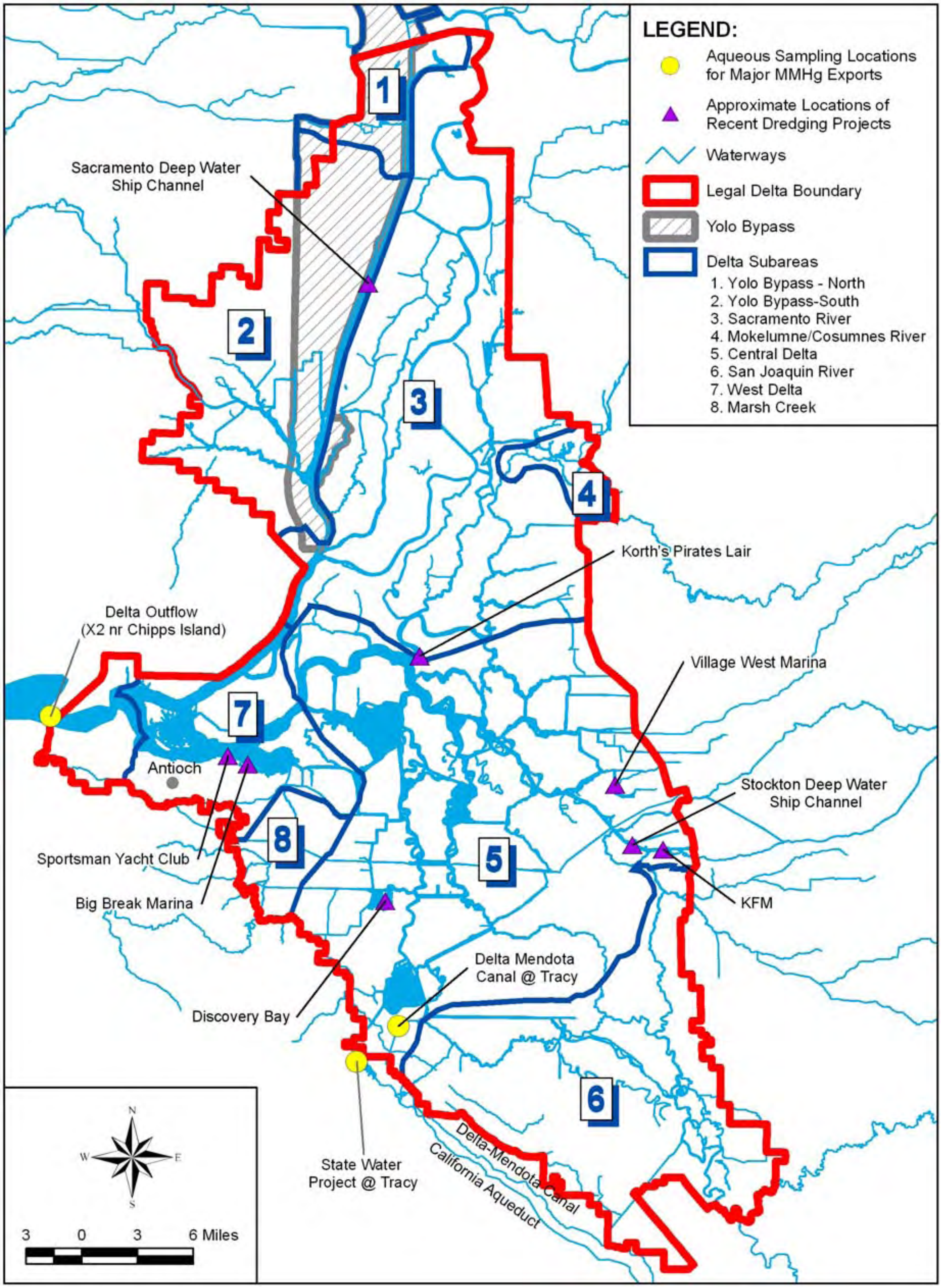

Figure 6.9: Aqueous Monitoring Locations for Major Methylmercury Exports and Approximate Locations of Recent Dredging Projects.

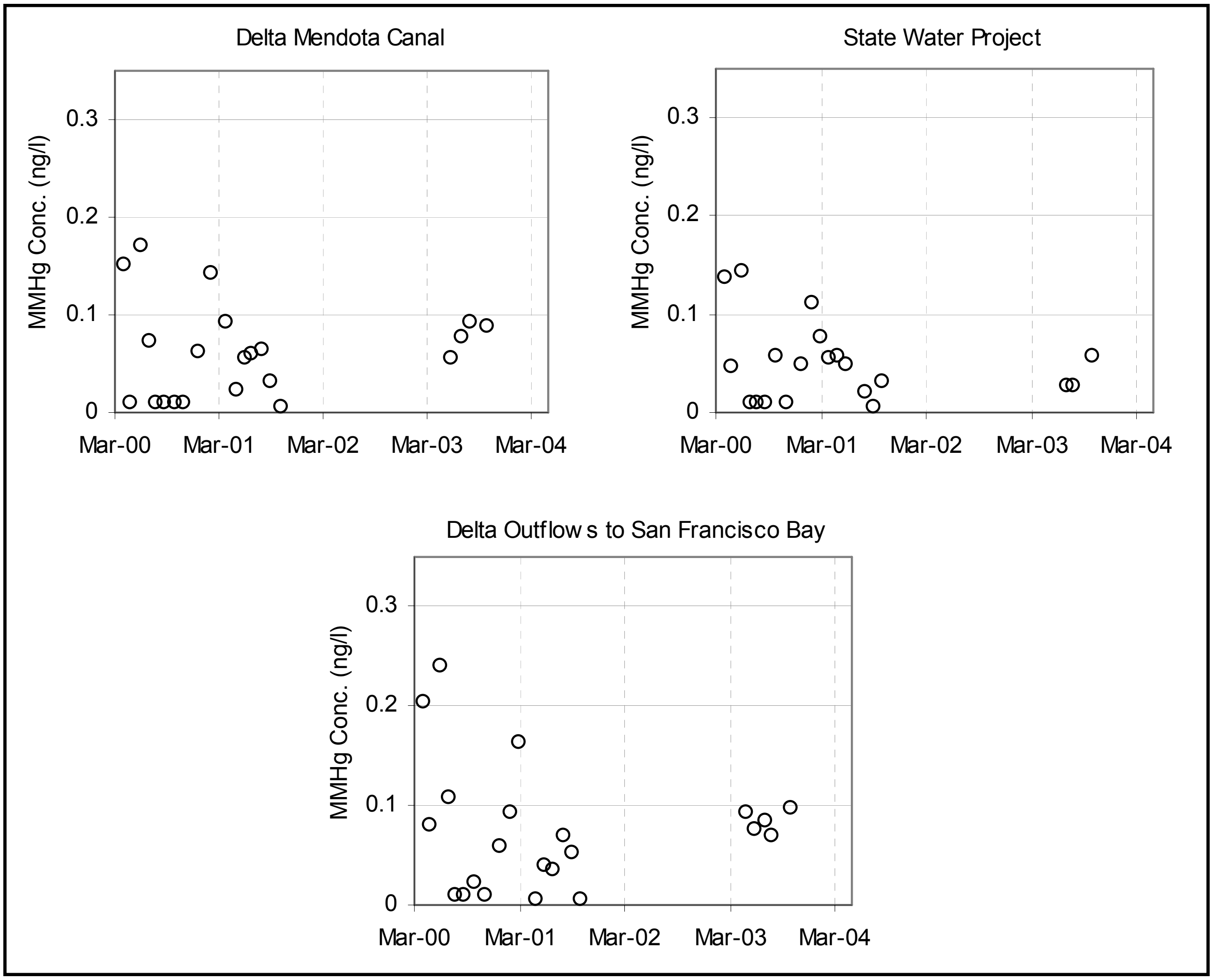

Figure 6.10: Available Methylmercury Concentration Data for the Delta's Major Exports

Table 6.17: Recent Dredge Projects within the Delta.

Delta Dredging Project	Project Location	Volume of Dredge Material (cubic yards)	Dredge Frequency	Disposal Location (upland, Delta island, wetland areas, etc.)	Mean Sediment Mercury Conc. (mg/kg, dry wt) [a]	# of Samples	Standard Dev.	T Value (p=0.975, conf 95%, df =n-1)	Total Weight of Mercury Removed (kg)	Annual Weight of Mercury Removed [a] (kg)	Annual Weight of Sediment Removed (Mkg, dry wt)	Annual Volume of Water Removed (acre-feet)	Does Effluent Return to a Receiving Water?	Average Effluent Hg Conc. (μg/l)
Sac. River Deep Water Ship Channel [b]	Sacramento River	199,000	Annually	Delta Island/ upland	0.37 ±3.93	2	0.4377	12.71	42	42 ±446 (n)	110.5	89.6	No	0.05 to 0.1
Stockton Deep Water Channel [c]	San Joaquin River	270,000	Annually	Delta Islands	0.083 ±0.023	28	0.0594	2.052	13	13 ±3.5	150.0	121.5	No	0.05 to 0.13
Village West Marina [d]	14-Mile Slough	70,000	Every 10 years	Delta Islands	0.043 ±0.014	3	0.0058	4.303	1.7	0.2 ±0.057	3.9	3.2	Yes [l]	0.05
KFM [e]	San Joaquin River	3,000	One time	Upland	*Unknown*						1.7	1.4	No	0.05
Korths Pirates Lair [f]	Mokelumne River	15,000	Every 5 years	Upland	0.15 ±0.11	2	0.0120	12.71	1.3	0.25 ±0.18	1.7	1.4	No	0.05
Big Break Marina [g]	San Joaquin River	12,000	Every 5 years	Upland	0.41 ±0.24	6	0.2318	2.571	2.8	0.55 ±0.33	1.3	1.1	No	0.25
Sportsman Yacht Club [h]	San Joaquin River	10,000	Every 5 years	Upland	0.12 ±0.014	3	0.0058	4.303	0.70	0.14 ±0.016	1.1	0.9	No	0.05
Discovery Bay [i]	Delta	50,000 [j]	Annually	Upland	0.027 ±0.018	7	0.0195	2.447	0.78	0.78 ±0.51	27.8	22.5	Yes [k, l]	0.05
Annual Averages [m]		**533,400 cubic yards**								**57 ±451 kg** [n]	**349 Mkg**	**241 a-ft**		

(a) The uncertainty of the mercury load values was estimated by calculating the 95% confidence interval for the mean of the concentration data for each project.
(b) U.S. Army Corps of Engineers, 2002 NOI (Notice of Intent) Sacramento DWSC.
(c) U.S. Army Corps of Engineers, 2000-2003 NOI Stockton DWSC.
(d) DCC Engineering Co, Inc., Village West Dredge Material Test, September 5, 2000.
(e) KFM, 401 Water Quality Certification.
(f) Anderson Engineers, 2003 Sediment Sampling and Analysis Plan for Korths Pirates Lair.
(g) Subsurface Consultants, Inc., Environmental Site Assessment 2001 & Aquifer Sciences, Inc., Pre-Dredge Sampling and Analysis Plan July 29, 2003.
(h) Padre Associates, Inc., Laboratory Analytical Results of Proposed Dredge Material and Associated Waste Classification May 23, 2003.
(i) Kennetic Laboratories/ToxScan, Inc., Sediment Properties and Chemistry April 2002, Discovery Bay, 2003 Final Water Quality Monitoring Report, WDR Order No. R5-2003-0027.
(j) Discovery Bay assumptions: The initial dredge project was 153,000 cubic yards, and 50,000 cubic yards/year thereafter. Therefore, assume 50,000 cy/year.
(k) WDR Order N. R5-2003-0027 indicates effluent returned to Discovery Bay averaged 3 mgd for several days to several weeks; staff assumed discharge period is 14 days/year.
(l) Two dredging projects, Village West Marina and Discovery Bay, had effluent that returned to Delta waters. The volume of effluent returned to receiving waters by the Discovery Bay project was approximately 42 million gal/year. The volume of effluent returned by the Village West Marina project is unknown. Staff estimated that the annual weight of mercury returned by the Discovery Bay dredge effluent was 0.008 kg, assuming that all water was returned.
(m) Annual averages do not include KFM, a one-time project.
(n) The uncertainty associated with the amount of mercury removed by dredging in the Sacramento Deep Water Ship Channel is particularly substantial (±446 kg), as a consequence of its calculation being based on only two sample results (0.68 and 0.061 mg/kg mercury) that have a tenfold range.

Table 6.18: MeHg:TotHg in Deep Water Ship Channel Surficial Sediments

	MeHg Conc. (ng/g)	**TotHg Conc.** (ng/g)	**MeHg:TotHg Ratio**
Sacramento Deep Water Ship Channel (a)			
Sacramento River DWSC	0.49	194.70	0.0025
Stockton Deep Water Channel (a)			
Little Connection Slough	0.20	82.51	0.0024
Headreach Cutoff	1.86	89.46	0.0208
Port of Stockton Turnabout #1	0.32	193.78	0.0017
Port of Stockton Turnabout #2	0.32	130.30	0.0025
		AVERAGE RATIO:	**0.006**

(a) Source: Heim *et al.*, 2003. Latitude/longitude coordinates provided with the above samples indicated that these were collected within the dredged deep water ship channels.

6.4 Delta Methylmercury Mass Budget & East-West Concentration Gradient

Figure 6.11 provides an idealized illustration of the Delta's average daily methylmercury imports and exports based on the annual loads presented in Tables 6.2 and 6.15. *In situ* sediment production and tributary water bodies account for about 35 and 58%, respectively, of methylmercury inputs to the Delta. Agricultural return flow and NPDES-permitted wastewater treatment plants are responsible for about 6% of the load while runoff from urban areas within the Delta/Yolo Bypass contributes about 0.4%.

The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. As noted in Section 6.2, the sum of WY2000-2003 water imports and exports balances within approximately 5%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. Average annual methylmercury inputs and exports were approximately 14.3 g/day (5.2 kg/yr) and 6.7 g/day (2.5 kg/yr), respectively (Tables 6.2 and 6.15 and Figure 6.11). Exports are only about 50% of inputs, suggesting that the Delta acts as a net sink for methylmercury.

A special study was conducted in the summer of 2001 to ascertain the location where much of the decrease in methylmercury occurred (Foe, 2003). Three transects were run down the Sacramento River and out toward San Francisco Bay, the water path from the main tributary source (Sacramento River) to the main export of methylmercury (Suisun Bay). The largest decrease in concentration consistently occurred in the vicinity or immediately downstream of Rio Vista (Figure 6.12). The drop in concentration was between 30 and 60%. The processes contributing to the loss are not known but are the subject of ongoing CALFED research (ERP-02-C06-B, Tasks 5A and 5B). For example, as described in the previous section, preliminary photodegradation study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' extrapolation of their preliminary study results over all Delta waters suggests a loss of about 4 g/day, which could account for more than 50% of the 7.6 g/day unknown loss rate illustrated in Figure 6.11.

Additional research is ongoing or proposed in Chapter 4 of the draft BPA report (Implementation) that includes monitoring to better characterize source concentrations and loads. Improvements made to the load estimates could affect the methylmercury load allocations calculated in Chapter 8.

Key points for the methylmercury source analysis are listed after Figures 6.11 and 6.12.

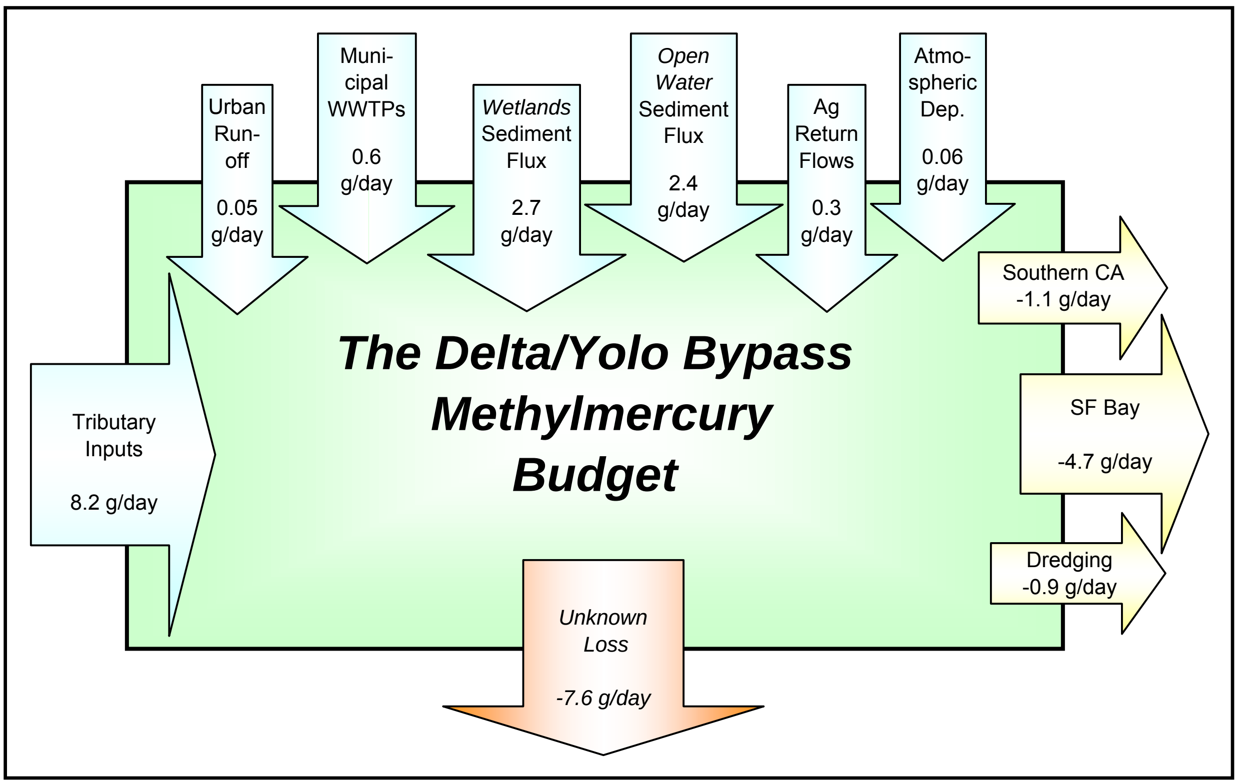

Figure 6.11: Average Daily Delta/Yolo Bypass Methylmercury Inputs and Exports. The rate of unidentified loss processes was determined by subtracting the sum of the inputs from the sum of the exports.

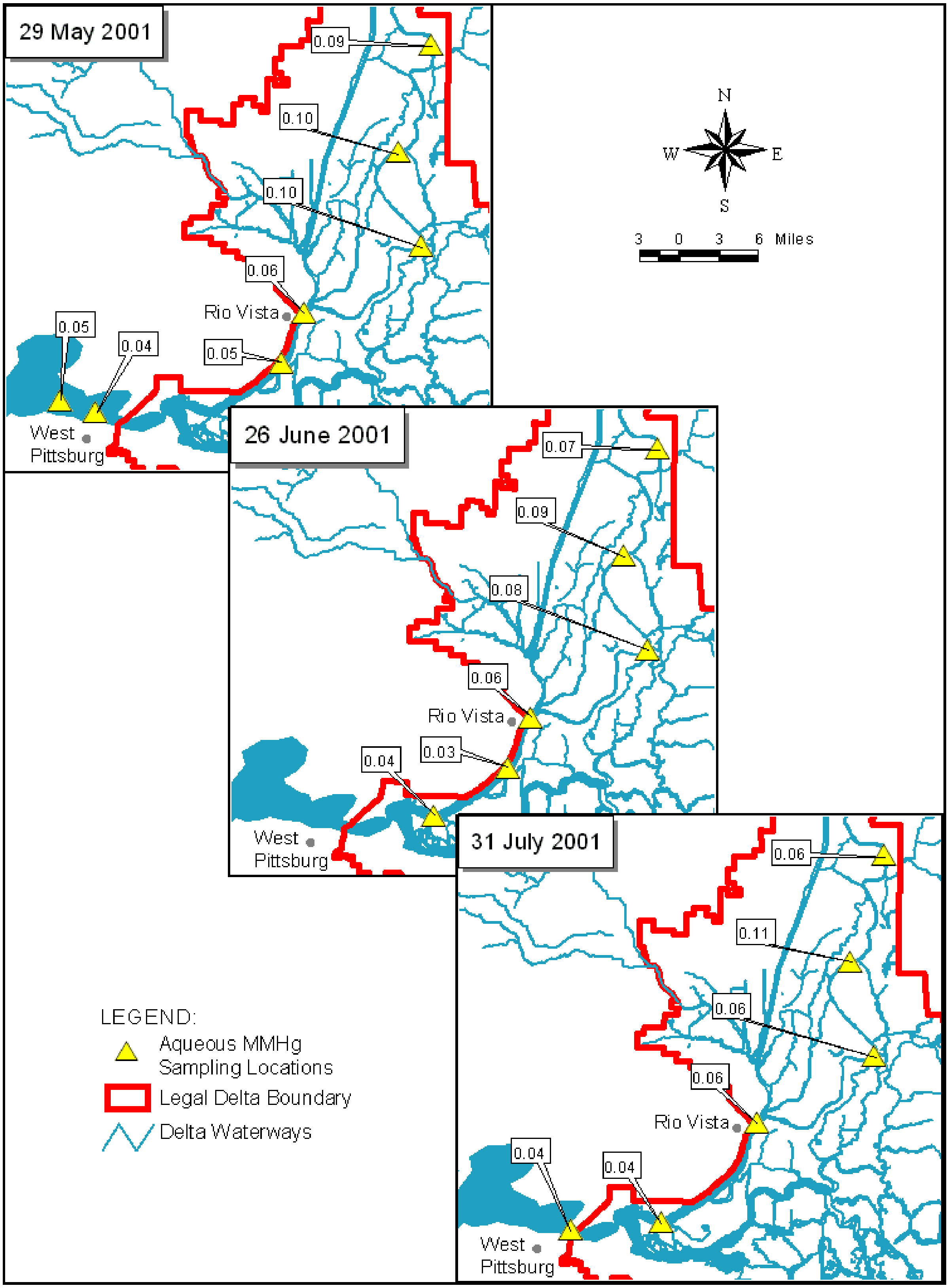

Figure 6.12: Water Sampling Transects down the Sacramento River to Ascertain Location of Methylmercury Concentration Decrease. Westernmost sampling stations changed with each transect depending on the locations of 1 o/oo through 5 o/oo bottom salinities, which move as a function of tidal cycle and freshwater inflow. (Data source: Foe, 2003.)

Key Points

- Sources of methylmercury in the Delta/Yolo Bypass include tributary inflows from upstream watersheds and within-Delta/Yolo Bypass sources such as methylmercury flux from sediment in wetland and open water habitats, municipal and industrial wastewater, agricultural drainage, and urban runoff. Approximately 58% of identified methylmercury loading to the Delta comes from tributary inputs while within-Delta sources account for approximately 42% of the load.
- Losses include water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, uptake by biota, and unknown loss term(s). Outflow to San Francisco Bay accounted for about 70% of identified methylmercury exports.
- The sum of WY2000-2003 water imports and exports balances within approximately 5%, and the sum of WY2000-2003 water imports and exports balances within approximately 1%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. A comparison of the sum of identified inputs (5.2 kg/yr) and exports (2.5 kg/yr) indicates that there is an unknown loss term of approximately 50%. Preliminary study results suggest that photodegradation may explain more than 50% of that loss term.